ENHANCING THE E-COMMERCE EXPERIENCE THROUGH HAPTIC FEEDBACK INTERACTION

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Doctor of Philosophy

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Abstract

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Tile: Enhancing the E-Commerce Experience through Haptic Feedback Interaction

The sense of touch is important in our everyday lives and its absence makes it difficult to explore and manipulate everyday objects. Existing online shopping practice lacks the opportunity for physical evaluation, that people often use and value when making product choices. However, with recent advances in haptic research and technology, it is possible to simulate various physical properties such as heaviness, softness, deformation, and temperature. The research described here investigates the use of haptic feedback interaction to enhance e-commerce product evaluation, particularly haptic weight and texture evaluation. While other properties are equally important, besides being fundamental to the shopping experience of many online products, weight and texture can be simulated using cost-effective devices.

Two initial psychophysical experiments were conducted using free motion haptic exploration in order to more closely resemble conventional shopping. One experiment was to measure weight force thresholds and another to measure texture force thresholds. The measurements can provide better understanding of haptic device limitation for online shopping in terms of the availability of different stimuli to represent physical products. The outcomes of the initial psychophysical experimental studies were then used to produce various absolute stimuli that were used in a comparative experimental study to evaluate user experience of haptic product evaluation.

Although free haptic exploration was exercised on both psychophysical experiments, results were relatively consistent with previous work on haptic discrimination. The threshold for weight force discrimination represented as downward forces was 10 percent. The threshold for texture force discrimination represented as friction forces was 14.1 percent, when using dynamic coefficient of friction at any level of static coefficient of friction. On the other hand, the comparative experimental study to evaluate user experience of haptic product information indicated that haptic product evaluation does not change user performance significantly. However, although there was an increase in the time taken to complete the task, the number of button click actions tended to decrease. The results showed that haptic product evaluation could significantly increase the confidence of shopping decision. Nevertheless, the availability of haptic product evaluation does not necessarily impose different product choices but it complements other selection criteria such as price and appearance.

The research findings from this work are a first step towards exploring haptic-based environments in e-commerce environments. The findings not only lay the foundation for designing online haptic shopping but also provide empirical support to research in this direction.

بسم الله الرحمن الرحيم

In the name of God, Most Gracious, Most Merciful

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Glossary of Abbreviations

2D	Two Dimensions
2.5D	Two and a half Dimension
3D	Three Dimensions
AJAX	Asynchronous JavaScript and XML
API	Application Programming Interface
B2B	Business-to-Business
B2C	Business-to-Consumer
C2C	Consumer -to-Consumer
DHTML	Dynamic Hypertext Markup Language
DoF	Degrees of Freedom
DynamicCF	Dynamic Coefficient of Friction
E-Commerce	Electronic Commerce
G2B	Government -to-Business
G2C	Government -to-Consumer
GUI	Graphical User Interface
HAPI	Haptic Application Programming Interface
HPI	Haptic Product Information
ISO	International Standardisation Organisation
JND	Just Noticeable Difference
JNDL	Lower Just Noticeable Difference
JNDU	Upper Just Noticeable Difference
N	Newton
Non-HPI	Non Haptic Product Information (i.e. textual)
PSE	Point of Subjective Equality
SDK	Software Development Kit
ST	Standard Stimuli
StaticCF	Static Coefficient of Friction
VE	Virtual Environment
VR	Virtual Reality
UI	User Interface

Declaration

No part of the material provided has previously been submitted by the author for a higher degree at Durham University or at any other University. All the work presented here is the sole work of the author and no-one else. The following publications were produced during the course of this thesis:

- Bamarouf, Y. A. and Smith, S. P. (2011). Exploring frictional surface properties for haptic-based online shopping. In: *Proceedings of the Joint Virtual Reality Conference of EuroVR*, Nottingham, UK, Eurographics Association, pp. 47 – 54.
- Bamarouf, Y. A. and Smith, S. P. (2011). Enhancing web retailing: Shopping with a sense of touch. In: *Proceedings of the 5th Saudi International Conference*, University of Warwick.
- Bamarouf, Y. A. and Smith, S. P. (2010). Evaluating virtual weights for haptically enabled online shopping. In: *Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology*, Hong Kong, ACM, pp. 179-180.
- Bamarouf, Y. A. (2009). TR-TEL-09-01: Haptic interaction as a purchase motivator in online shopping. In: *Innovative Computing Group Technical Report Series*, Durham University.

Statement of Copyright

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Dedication

I dedicate this thesis to my family, especially…

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Chapter 1: Thesis Introduction

1.1 Introduction

This chapter provide an overview of the thesis, beginning by presenting the research problem. After setting out the scope of the thesis, the following sections state the aims and objectives and the methodology followed to achieve these aims. Finally, the chapter concludes with a discussion of this thesis's contribution to existing research and provides an outline of the entire work.

1.2 Research Overview

The rapid expansion of the Internet and electronic commerce (e-commerce) has encouraged many consumers to buy a variety of products online. From the consumers' point of view, e-commerce offers a convenient way to find products, resulting in spending less time and effort (Schaupp and Bélanger 2005). With the help of online comparison tools, shoppers can compare prices and product features to make a better selection from the comfort of their homes. However, unlike conventional shopping, online shoppers most often have to rely on what is presented to them visually (Chau et al. 2000; Blanco et al. 2010). Visual information, such as videos, animations and product images, is usually used to accompany textual descriptions to express product characteristics. Therefore, it is essential that online retailers have sufficient product information, as this is one of the most important ways to satisfy consumers' needs (Ballantine 2005; Blanco et al. 2010). This is especially true for products that cannot be fully experienced online, such as apparel and electronics (McCabe and Nowlis 2003; Spence and Gallace 2011); for instance, apparel may not feel as soft as expected when worn, or electronic devices may not feel as light.

Electronic retailers now compete by offering interactive high-quality content to consumers to attain a competitive advantage (Blanco et al. 2010). Web developers and designers are increasingly using technologies like DHTML (Dynamic HTML), AJAX (Asynchronous JavaScript and XML) and Flash[1] to enhance the interactivity of e-commerce websites (Borodin et al. 2008), but existing e-commerce systems on the Web provide users with relatively simple, mouse-based interaction for browsing through available products. This long-established method of interaction lacks physical evaluative criteria, which is an important elements in evaluating many products (Spence and Gallace 2011). Hwang et al. (2006) note the need for online physical contact with products to gain product information through first-hand knowledge, which is often experienced in a conventional shopping environment. The lack of such interaction is likely to deter individuals from engaging in e-commerce practice (Childers et al. 2001). Reflecting on the experience of shopping online, Gleckman (2000) states "I still want to see and touch a product before I buy it. Websites are pretty good for selling books and airplane tickets. But they don't do feel".

[1] http://www.adobe.com [last accessed 12/03/2011].

Haptic[2] feedback interaction is a growing field of research in science and engineering (Saddik et al. 2011b). Through haptic interfaces users can touch and feel the properties of virtual objects such as their weight, smoothness and warmth. In recent years, there has been an increasing interest in haptic research (Saddik et al. 2011b). As a result, haptic technology is gradually gaining strength and breadth through increasingly wider applications. It has been used in many areas such as education and training, entertainment, industry, engineering, and marketing to enhance the interaction experience. As the demand for touch interaction increases, desire for haptic feedback interaction continues to flourish. However, supporting e-commerce applications through the use of haptic feedback interaction to enhance user experience is one of the least-investigated areas. Studies conducted by Shen et al. (2003), Cha et al. (2005) and Funahashi et al. (2009) are among the few that have addressed the potential of haptic feedback interaction to enhance online shopping experience.

Traditionally, haptic feedback devices were bulky, expensive to buy, and required technical expertise to install and use. Such specifications have been regarded as constraints in the feasibility of incorporating haptic feedback interaction into e-commerce applications. This perceived infeasibility has meant that less attention has been drawn to the field. However, recent innovations in the gaming industry have seen a marked increase in haptic peripherals, such as rumble packs in game pads/steering wheels, and gaming devices are increasingly able to support haptic

[2]The term "haptic" is a Greek word associated with the science of sensing through touch (Eid et al. 2007). Refer to section 2.2 for a more detailed discussion.

interactions. Other commercial haptic technologies have included the Novint Falcon[3], released in 2006, which provides cheap high-fidelity haptic interaction intended for video games and the Phantom Omni[4], a portable, cost-effective haptic device. The latter technologies are of particular interest here since they are small in size and able to provide a variety of haptic interactions, including the simulation of haptic weight and texture forces, both of which are fundamental to the shopping experience of many products that people may wish to shop for online. If haptic-based shopping were to be adopted in the future, these advantages are likely to be among the characteristics of the ideal device.

A key difference between traditional and online shopping is the ability to physically perceive and compare product offerings (Spence and Gallace 2011). Such perception, conveyed through the human haptic sensory system, allows us to make judgments about the perceived stimuli in the physical world that otherwise we would have difficulty making. Indeed, in order to incorporate haptic feedback interaction into online shopping, shoppers must able to discriminate between various haptic weight and texture force properties for effective online product comparison. Essentially, perception is measured using psychophysical methods of threshold or just noticeable difference (JND) to effectively discern the difference between two haptic stimuli's intensities. While prior research has established JNDs for human subjects, none to the author's knowledge has tailored its findings to the online shopping domain.

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[3] http://home.novint.com [last accessed 26/03/2011].

[4] http://www.sensable.com [last accessed 26/03/2011].

This thesis examines human perception of haptic weight and texture force stimuli for online shopping contexts using psychophysical methods of measurement. This will provide a step towards defining surface differential thresholds for online shopping and other haptic-based applications that require evaluative comparisons. This thesis also investigates the use of haptic feedback to introduce touch interaction into the e-commerce arena. The proposed haptic interaction integration will provide shoppers with a richer product evaluation experience for web retailing. This experiment allows us to study empirically the usability of such interaction in terms of performance and subjective satisfaction. It is believed that this integration is promising for at least two reasons: i) it provides a more natural mode of interaction, and ii) it offers the ability to experience a product personally through an interactive media.

1.3 Research Scope

Haptic feedback interaction has the potential to enhance the usability experience of computer systems and applications. Current work on providing haptic feedback has focused mainly on the experience it provides in various computer-based applications, such as education and training. The present study focuses on the usability experience of haptic interaction in e-commerce; however, the scope of this research is limited in several respects. First of all, the experience is limited to physical products. Virtual products, such as music, movies, and e-books, are beyond the scope of the thesis. While there are other commercial haptic devices that could be employed, this study only used the Phantom Omni haptic feedback device to interact with the experimental e-commerce prototypes and to generate different haptic sensations. Furthermore, the generated haptic product sensations are limited to weight and texture, given that other haptic properties that are important in shopping, such as temperature, cannot be simulated using the device utilised in this research. While weights are generated as a downwards-pushing force, textures have several dimensions (e.g., roughness, softness). However, this study restricts these dimensions to frictional force, often associated with texture smoothness (Hollins et al. 2000). While the realism of the simulated haptic sensations is important when evaluating product information, this study focuses on the users' experience of the sensations in the context of online shopping.

1.4 Overall Aims

The work sets out to investigate the use of haptic feedback in an attempt to enhance product evaluation in e-commerce websites, thereby also enhancing the online shopping experience (Zhou et al. 2007). The proposed shopping environment provides methods through which users can "feel" products, which offers a richer electronic retailing experience. The feeling to human subjects is to be haptically simulated to allow comparisons of different stimuli. This requires a deep understanding of what human subjects can perceive in terms of differences between various haptic stimuli. While the ultimate aim is to measure the usability experience of the proposed interactive shopping environment, gaining insight into the design space for multiple comparisons of simulated haptic information, which is required to support online shopping, is a further aim of this investigation. The two main goals of this thesis are set out below.

Aim 1: To investigate the smallest haptic stimuli difference, often referred as the just noticeable difference (JND), needed to effectively discern between two close haptic stimuli levels for the online shopping context using psychophysical methods of measurement.

Aim 2: To investigate the use of haptic product information as an enhancement to textual product information to enhance the electronic shopping experience. Performance measures such as time and effort needed to complete tasks, as well as the subjective satisfaction experience of the interactive shopping environment, are used to measure the enhancement effect.

1.5 Overall Objectives

In order to fulfil the above aims, four different experimental platforms were developed. Two of these platforms were to carry out two initial psychophysical experiments regarding users' perceptions of haptically simulated stimuli (*Aim 1*), namely, weight and texture. The other two platforms were e-commerce prototypes that facilitated the use of a range of textual and simulated haptic product information. These prototypes were manipulated via a haptic environment, which offers users both visual and haptic feedback to allow for experimental comparisons (*Aim 2*). In particular, the platforms were meant to empirically compare textual-based product information (Non-HPI) haptic environment with a haptic-based product information (HPI) haptic environment.

1.6 Method

Figure 1.1 shows the structure of the thesis in terms of the experimental steps followed in this research. The thesis began by reviewing the literature to identify gaps in existing haptic research and its use to enhance e-commerce user experience.

After reviewing the literature, two initial psychophysical research experiments to measure JND threshold were conducted to address the aims outlined in section 1.4. The first of the two initial psychophysical experiments evaluated haptic weight discrimination with a group of 24 subjects. The other psychophysical experiment evaluated haptic frictional surface discrimination with a group of 20 subjects.

The outcomes of the initial psychophysical research were then used to produce various absolute stimuli that were later used in the comparative study to evaluate the user experience of haptic product information. The user experience evaluation was conducted with a group of 24 subjects to collect performance measures (i.e. effectiveness and efficiency) and subjective satisfaction measures through questionnaires. Subsequently, the findings from the three experimental studies were discussed and explored regarding the use of haptic feedback to enhance the interaction experience of e-commerce websites. Finally, conclusions are then drawn from this research and future work is suggested.

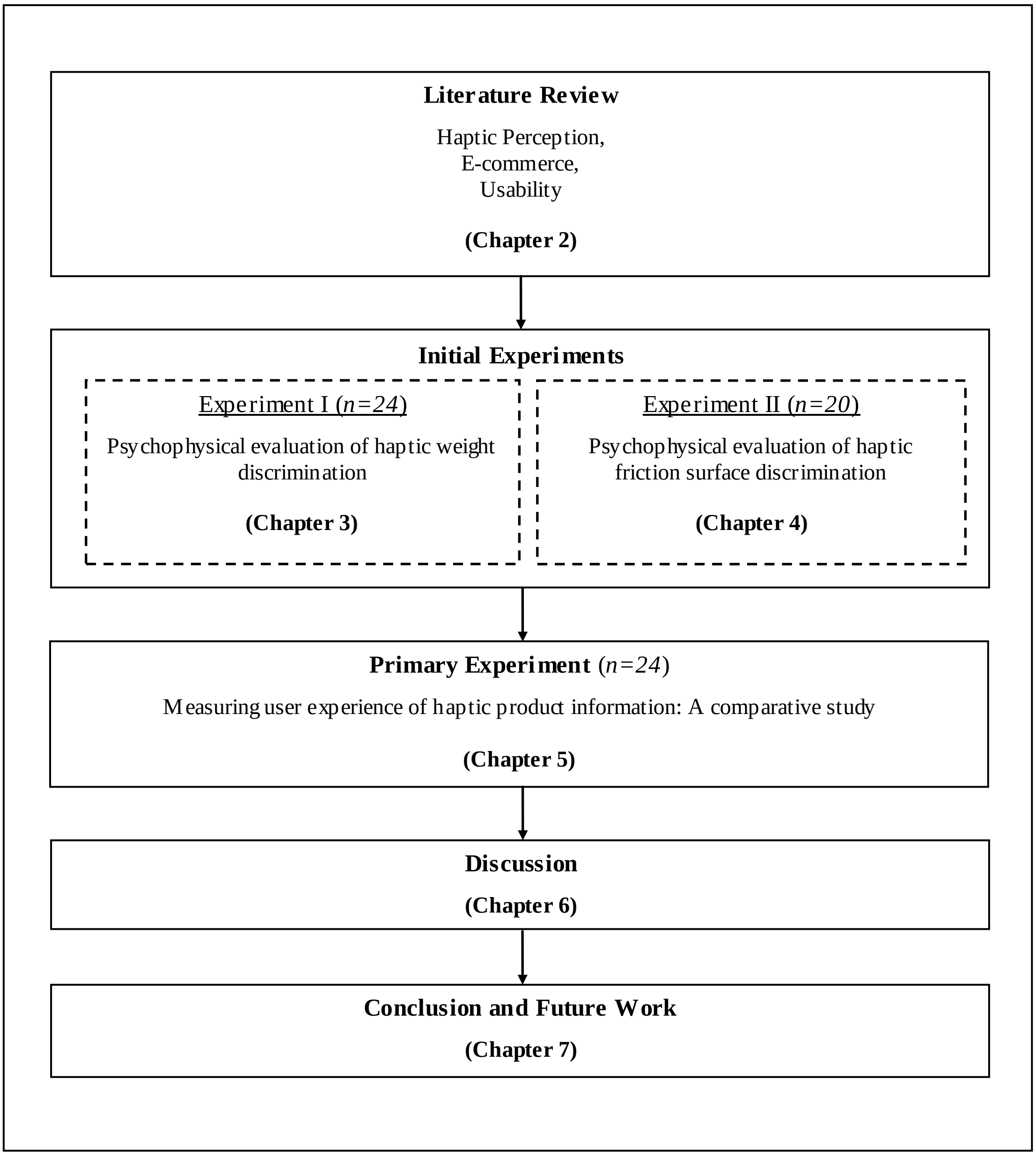

Figure 1.1: Structure of the thesis in terms of the experimental steps followed in this research process.

1.7 Contribution to Knowledge

This thesis contributes to two major research areas: haptic perception and e-commerce usability. In the area of haptic perception research, it provides discriminative haptic stimuli sensation using experimental psychophysical techniques to measure thresholds. More specifically, the contribution lies in measuring two haptic stimuli thresholds (i.e., weight and frictional texture) with free-motion haptic exploration to support evaluation practices like those often performed in conventional shopping.

In terms of e-commerce usability, this study points towards a more usable e-commerce design for enhanced information content through haptic perception. The core contribution here lies in the empirical comparison between dissimilar store information content to assess which condition best enhances online shopping information content. Most particularly, it measures the effects on efficiency, effectiveness and satisfaction of two conditions, the textual-based product information condition against an enhanced product information condition that uses haptic feedback stimuli. Based on the outcomes of this research, design recommendations are given with regards to adding haptic feedback to enhance electronic shopping. These contributions to knowledge will be revisited and discussed in the final chapter (Chapter 7) of this thesis.

1.8 General Outline

The outline of the thesis is as follows:

Chapter 2 discusses haptic perception, with a brief overview of the human sensory system and how real-world interactions can be replicated using haptic simulation via haptic devices. It also looks into methods for measuring human sensory perceptions through psychophysical measurements. The challenges of haptic technology are also discussed in this chapter. The chapter then provides an overview of e-commerce and online shopping. It discusses e-commerce usability and its importance, as well as current trends in e-commerce content design. The issues and challenges of e-commerce are also discussed in this chapter, which highlights some of the challenges that act as constraints and the prospects that are factors in implementing a successful and sustainable e-commerce system. While there are many challenges, current e-commerce websites are limited because consumers are unable to “feel and touch” products, which may affect their confidence in the chosen products. Finally, usability studies on haptics are also reviewed in terms of their impact on users’ performance and experiences.

Chapter 3 reports an experimental study that was conducted to evaluate human perception of haptic weight force. Psychophysical measurement methods were employed to identify the smallest haptic stimuli difference (i.e., JND) needed to effectively discern between haptic stimuli for online shopping context.

Chapter 4 reports another experimental study that was conducted to evaluate human perception of haptic surface friction force. Psychophysical measurement methods were employed to identify the smallest haptic stimuli difference (i.e., JND) needed to effectively discern between haptic stimuli for online shopping context.

Chapter 5 describes a comparative investigation of the role of haptic feedback integration to improve e-commerce usability and enhance product evaluation in e-commerce websites. Performance measures, as well as the subjective satisfaction experience of the interactive shopping environment, are the main topics of this chapter.

Chapter 6 presents a general discussion on the experimental evaluations conducted in this study, including a reflection upon the approaches undertaken to tackle various technical, operational, and economic issues.

Chapter 7 brings together the key contributions of this research. It summarises the findings and shows their significance for various communities, including researchers, designers of online shopping, and users of online shopping. The chapter also presents the limitations of the research and offers suggestions for future research.

Chapter 2: Literature Review

2.1 Introduction

In order to enhance the e-commerce experience through haptic feedback interaction, it is necessary to have an adequate understanding of several research areas. This chapter starts with a section providing a brief historical overview of haptic perception research of the human sensory system as well as looking at ways in which such sensory is psychophysically measured. The section then reviews haptic feedback in terms of the rendering process, the range of feedback devices and different applications that make use of haptic feedback technology. A section on e-commerce then briefly underlines its potential and the benefits it offers to businesses and consumers. Both sections conclude with a consideration of the challenges associated with haptic feedback interaction and e-commerce in order to identify the gaps in current research that this thesis can help fill. The chapter ends with an overview of usability, with special attention paid to the characteristics that are important for enhancing the e-commerce experience, as well as current trends in enhancing e-commerce content design, for a complete picture of how haptic feedback can enhance the e-commerce experience. In addition, usability studies on various haptic applications that include e-commerce are considered.

2.2 Haptic Perception

In everyday human interactions, the process of receiving and sending of information is achieved by contributions from one or many sensory channels found in the human body. There are five human sensory channels of interaction: sight, hearing, touch, smell, and taste. Touch is experienced through the skin, and it plays a significant role in human survival. As a sensory channel, the skin is the largest sensory organ of the human body and the earliest to become functional (Fosshage 2000). Without the physical and behavioural functions performed by the skin, human existence becomes impossible (Fosshage 2000).

Beginning in the mid-1970s, there has been a rapid growth of interest in physical touch research in humans (Fosshage 2000). Derived from a Greek word, the term *haptic* (pronounced HAP-tiks) was associated with the science of sensing through touch (Carr and England 1995, p. 145). In the late 1980s, the term expanded to include machine touch and human–machine touch interactions experienced in real or virtual environments, or in a combination of both (Eid et al. 2007). In the early 1990s, the term *computer haptics* was introduced, which was associated with algorithms and the software to generate and render the touch and feel of virtual objects (Eid et al. 2007).

Technical literature in the field of haptic interaction uses the terms *touch* (also known as *tactile*) and *force* (also known as *kinaesthetic*) *feedback* to refer to different haptic modalities. Touch feedback is concerned with the contact surface information (roughness, slippage, temperature), without resisting the user's contact motion (Burdea and Coiffet 2003, p. 93). On the other hand, force feedback is concerned with the object's resistive information (compliance, weight, and inertia), which can resist the user's motion or completely stop it (Burdea and Coiffet 2003, p. 93). Touch and force feedbacks are often used together when exploring haptic objects virtually.

Haptic feedback interaction provides the necessary sensations involved in touch during the manipulation of virtual objects in a virtual reality (VR) environment. VR makes use of computer graphics systems in combination with various display and interface devices, such as data gloves, eye trackers, a three-dimensional (3D) mouse or trackball, and force-feedback devices, to provide the effects of immersion in the interactive 3D computer-generated environment; this environment is also sometimes referred as a virtual environment (VE) (Pan et al. 2006). Similar to computer graphics, computer haptics looks at the techniques and processes for generating and displaying haptic stimuli to the human user (Srinivasan and Basdogan 1997) (see Figure 2.1).

Like traditional visual and auditory feedback, haptic feedback is another channel of interaction in terms of conveying sensorial information but with different unique properties. Besides allowing users to achieve physically tangible interactions, haptic feedback improves the realism of the visual and auditory feedbacks in VEs. Hence, haptic feedback, when combined with the other senses, may provide a better perception of virtual information. This, in turn, further increases the realism of the perceived environment. Such interaction requires an in-depth understanding of the human haptic system in order to design and implement hardware and software that can replicate human sensations in the virtual world. Later sections will provide more details on the topic of haptic perception which will be limited to the human hand because the hand holds the highest density of touch receptors when compared to the other parts of the body (Burdea and Coiffet 2003, p. 93).

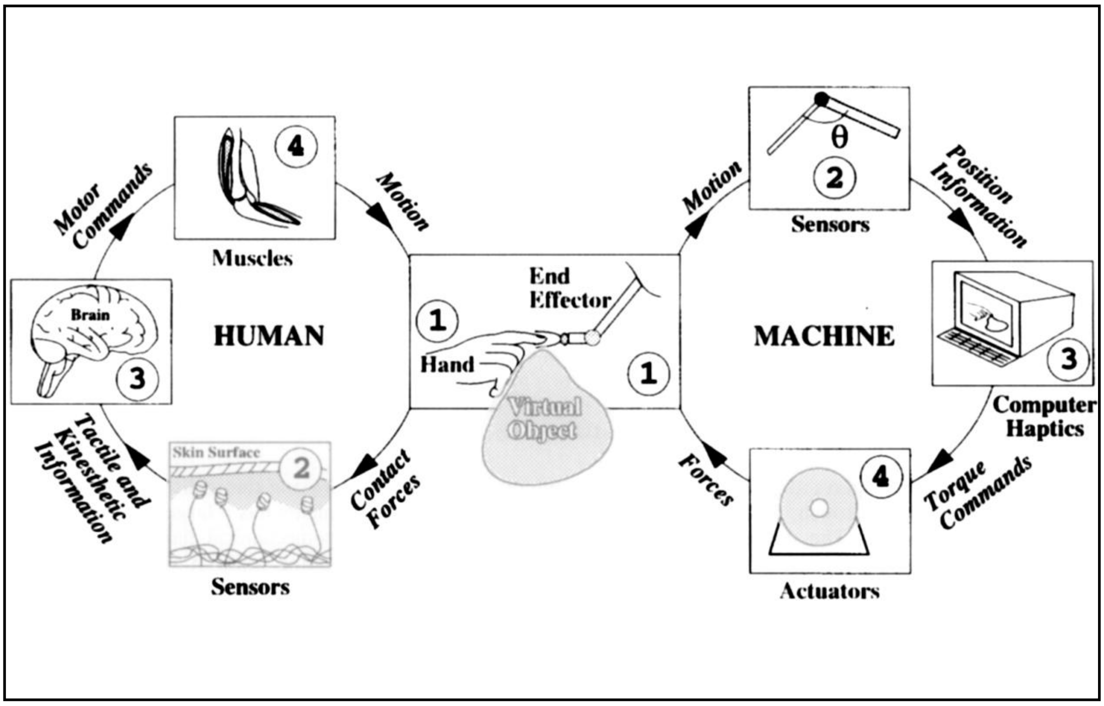

Figure 2.1: Haptic interaction between humans and machines (Srinivasan and Basdogan 1997).

2.2.1 The Human Haptic Sensory System

The human haptic system (see Figure 2.2) consists of the mechanical, sensory, motor and cognitive components of the hand-brain system (Srinivasan and Basdogan 1997). The mechanical component provides the degrees of freedom (DoF)[5] for everyday human body movements. For example, the human hand has a number of bones, joints and muscles to provide an approximate total of 25 DoF or ways of interacting with the environment around us (Miller 2004). The sensory component of the human haptic system allows for exploration and interaction with various surfaces in the environment (Göger et al. 2006). It consists of an enormous number of receptors and

[5] A higher number of DoF means incresed flexibility in movement.

nerve endings in the skin, which occupies the major surface area of the human body (Fosshage 2000). Appropriate mechanical, thermal, and chemical stimuli activate these receptors, causing them to transmit electrical impulses to the central nervous system, which, in turn, uses neurons to send commands to the muscles for the desired motor action (Srinivasan and Basdogan 1997).

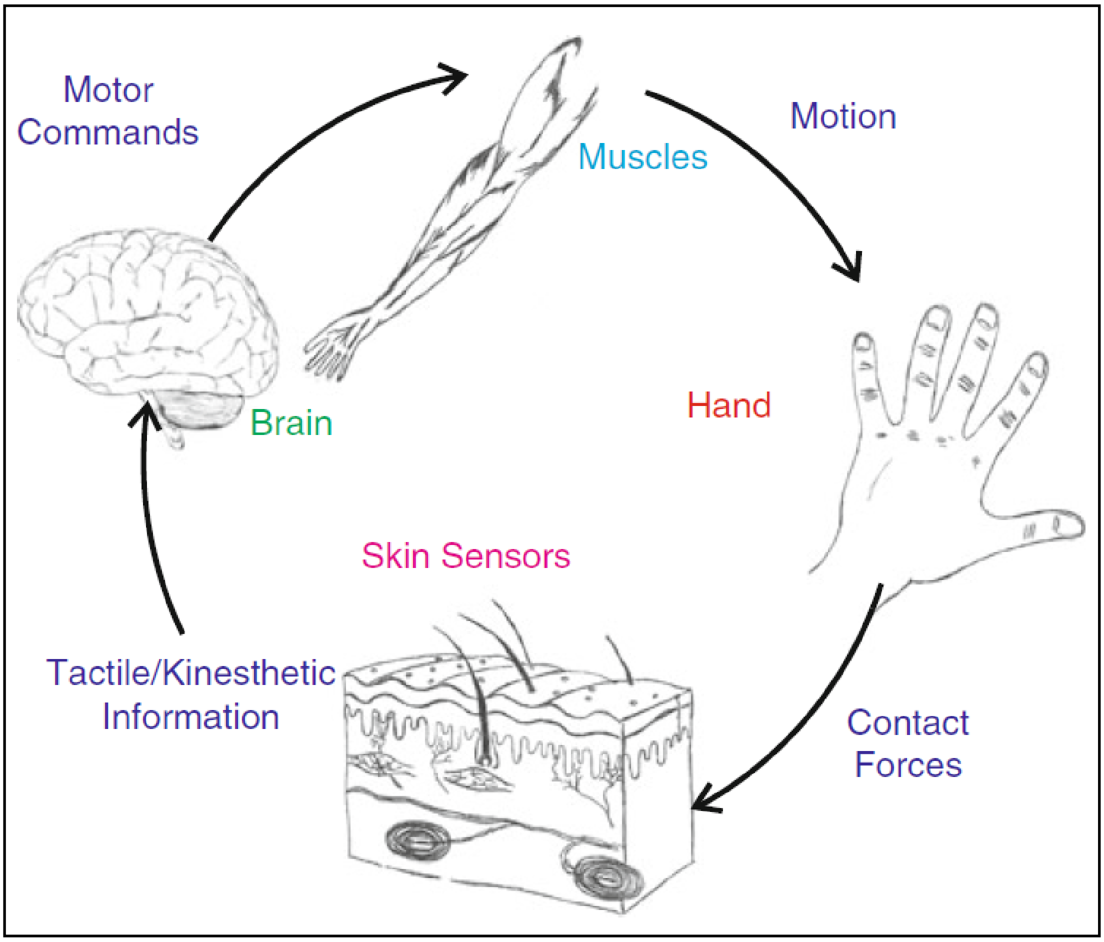

Figure 2.2: Human haptic system (Saddik et al. 2011a).

Tactile and kinaesthetic senses are fundamental components of the human haptic sensory system. Although they are usually addressed as separate components in the literature, they are often used together in everyday observations, as illustrated in Figure 2.3. Understanding both sensory stimuli is important because current haptic technology focuses on stimulating the human sensory system by sending artificial sensations to one or both human sensory components. The following subsections will describe these two types of sensory stimuli.

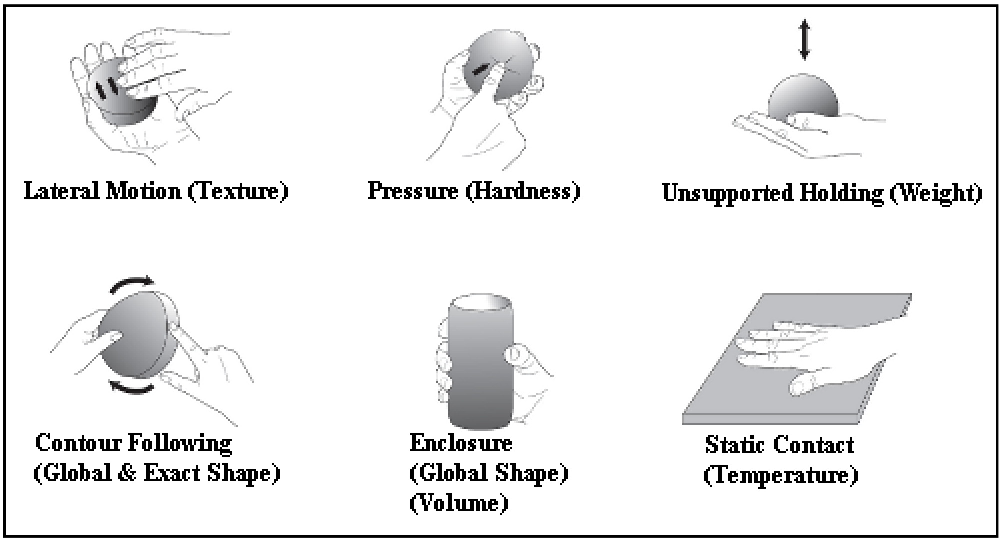

Figure 2.3: Manual exploratory procedures (Lederman and Klatzky 2009).

2.2.1.1 Tactile Sensing

Tactile sensing is an essential interaction system experienced by the skin of the human body. The lack of this sensory system would makes it hard to explore and to manipulate everyday objects in our environment. Skin's unique size and extension make it much more accessible than any other sensory system, such as sight or hearing. The skin is comprised of three types of sensory receptors: thermo-receptors, which respond to heat and cold; nociceptors, which respond to intense pressure, heat, and pain; and mechanoreceptors, which respond to pressure (Haans and Ijsselsteijn 2006). The final one is of interest in terms of tactile sensation in relation to the human–computer interaction. Mechanoreceptors found on different layers of the skin consist of Pacinian corpuscles, Meissner's corpuscles, Merkel's discs, and Ruffini corpuscles (Burdea and Coiffet 2003, p.94; Saddik et al. 2011a), as illustrated in Figure 2.4 below.

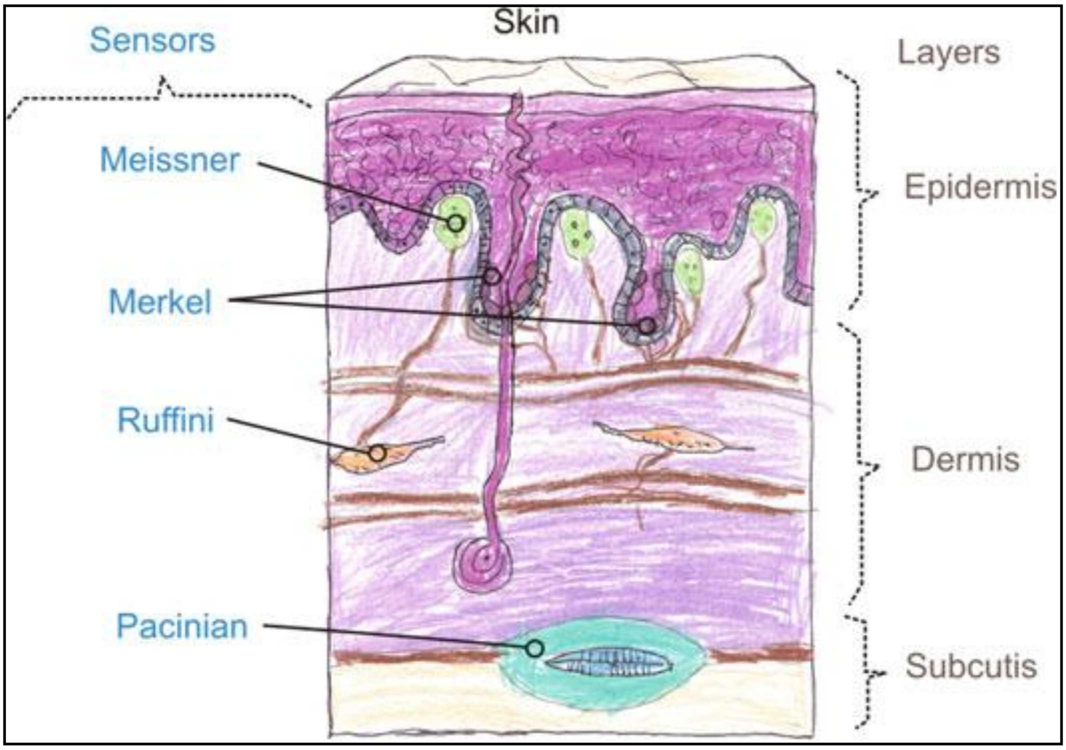

Figure 2.4: Mechanoreceptors sensors in the human skin (Saddik et al. 2011a).

As we interact with the environment around us, mechanoreceptors produce small electrical impulses sensed by the brain. The frequency range of the impulses, along with the size and density of the abovementioned receptors, classifies their sensitivity. Merkel's and Ruffini receptors detect sustained touch and pressure, and they are sensitive to low-frequency stimuli, whereas, Pacinian and Meissner's receptors detect deep pressure, rapid vibrations, and changes in texture, and they are sensitive to stimuli of higher frequencies (Burdea and Coiffet 2003, p.94). Table 2.1 summarises the characteristics of each of the four types of mechanoreceptors receptors responsible for tactile sensation in human skin.

	Stimulus Frequency (Hz)	Receptive Field	Detection Function
Merkel's discs	0 - 10	Small, well defined	Indentation, curvature
Ruffini corpuscles	0 - 10	Large, indistinct	Static force, skin stretch
Meissner's corpuscles	20 - 50	Small, well defined	Velocity, edges, slip detection
Pacinian corpuscles	100 - 300	Large, indistinct	Acceleration, Vibration through tool

Table 2.1: Comparison of Various Skin Mechanoreceptors (Burdea and Coiffet 2003, p.94).

2.2.1.2 Kinaesthetic Sensing

The kinaesthetic sense is concerned with sensing the human body's movement and position to be awareness of the muscles, tendons, and joints activities. Performing a simple activity such as picking up an apple would be a very difficult task without the correct angles and the correct muscle force required to lift the apple's weight. Kinaesthetic receptors, which are found in the joints and muscles, provide such information to the human central nervous system (Proske 2006). These receptors fall into three categories: muscle spindle receptors, to provide information on muscle length and rate of muscular contraction; Golgi tendon receptors, to sense muscle contraction force; and joint receptors, to sense joint angles (Proske 2006; Magnenat-Thalmann et al. 2007). The precision of the information sensed depends on the Just Noticeable Difference (JND) that can be detected, which affects both the comfort and the performance of human limbs (Burdea and Coiffet 2003, p.95). Muscle tiredness due to steady force can cause a rapid increase in force magnitude, which, in turn, may also play a role in our everyday dealings (Burdea and Coiffet 2003, p.95).

2.2.1.3 Human Sensory Measurement

In psychophysics, the differential threshold, also known as JND, is "the smallest amount of stimulus energy necessary produce a sensation" (Gescheider 1997, p. 1). It is the smallest amount of detectable difference between two stimuli intensities that cab be perceived by individuals. If, for example, two stimuli weighing 1 kg each were presented, and one of them was incrementally increased until it was just noticeably heavier, at 1.2 kg, then in this case, the 200 g would be the difference threshold.

In the early 19th century, while measuring the discrimination of lifted weights, German physiologist Ernst Weber discovered that the size of the difference threshold is a constant proportion of the original weight stimuli (Gescheider 1997, pp. 3 - 15). This extremely useful discovery is applicable to any other stimuli. In fact, other stimuli, such as sight, hearing, smell, or other conditions and modalities sensed by the human sensory organs, have constant proportions of their own (Gescheider 1997, pp. 3 - 15). This constant proportion of difference threshold can be calculated using what is known as Weber's Law, shown in Figure 2.5. The law implies that Weber's Fraction (c) is the result of the JND ($\Delta Ø$) divided by the original stimulus ($Ø$).

$$\Delta Ø / Ø = c$$

Figure 2.5: Weber's law

In reference to the weights example given earlier, the Weber's Fraction equivalent for the 200-g difference threshold would be 0.2 (200 g / 1000 g = 0.2). The Weber's Fraction of 0.2 can then be used to predict the JND needed to discriminate between any starting stimulus and a secondary one that has been increased (or decreased) using this Fraction value. For example, the difference between a stimulus weighing 1.5 kg and another stimulus will not be noticeable until the weight increases by 300 g or more (1.5 * 0.2 = 300 grams).

There are many methods for measuring the thresholds of human perception. According to Gescheider (1997, pp. 46 - 66), the method of constant stimuli, the method of limits and the method of adjustment developed by Fechner are the most commonly used methods of measuring thresholds. All of these revolve around the idea of presenting individuals with stimuli containing similar and different intensities while recording their perceptions. While the method of limits and the method of adjustment are far less time-consuming to administer, the method of constant stimuli is more precise, as the procedure requires that each stimulus trial be repeated with as few as five observers at least 20-100 times (Gescheider 1997, pp. 46 - 66; Ehrenstein and Ehrenstein 1999). However, such repetition appears to come at the cost of increased observer inaccuracy in responses due to the effects of adaptation, habituation, and sensitisation (Burro et al. 2011).

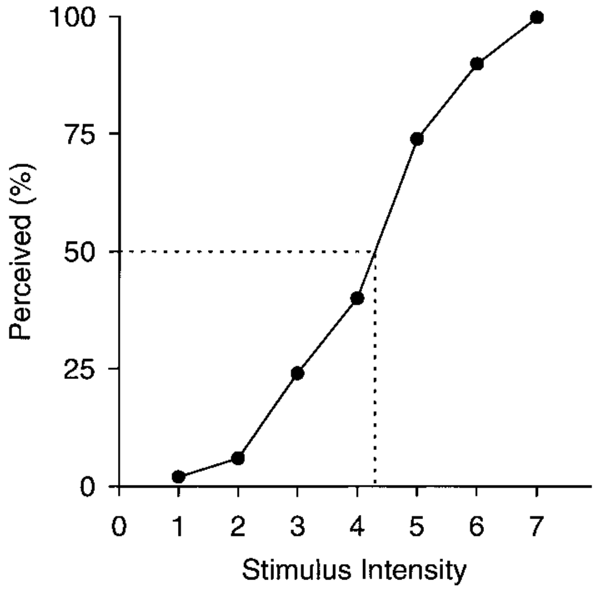

Figure 2.6: A typical psychometric function obtained when the thresholds of human perception are measured using the method of constant stimuli.(Ehrenstein and Ehrenstein 1999).

The graph in Figure 2.6 displays an example of what is obtained when the thresholds of human perception are measured using the method of constant stimuli. It shows the proportion of times a standard stimulus paired with a number of comparisons stimuli (usually between five and nine) is reported as having a greater intensity (Gescheider 1997, pp. 46 - 54; Ehrenstein and Ehrenstein 1999). The comparative judgment yields a sigmoid curve, as a function of the difference in contrast between the two stimuli. The proportion point of 0.50 on the psychometric function is known as the point of subjective equality (PSE) (Gescheider 1997, PP. 46 - 54; Ehrenstein and Ehrenstein 1999). This point represents a complete lack of discrimination, i.e., the point at which the comparison stimulus is perceived by the observers as equal to the standard stimulus. The proportion points of 0.25 and 0.75 on the psychometric function are used to find the JND threshold. The upper JND (JNDU) threshold is the stimulus ranging from the PSE to the 0.75 proportion point, whereas the lower JND (JNDL) threshold is the stimulus ranging from the PSE to the 0.25 proportion point. JNDU and JNDL can then be averaged to give one JND threshold that is used to calculate Weber's Fraction, which was discussed earlier in this section (Gescheider 1997, pp. 46 - 54; Ehrenstein and Ehrenstein 1999).

Another effective measurement method is the method of transitions proposed by Burro et al. (2011), which is a modification of the method of constant stimuli for measuring thresholds of human perception. The transition method helps to negate the effects of adaptation, habituation and sensitisation caused by the high volume of trial repetitions when using the method of constant stimuli in its traditional form (Burro et al. 2011). It follows a similar procedure to that implemented with the method of constant stimuli, with the difference being in the way the trial is repeated and the way the responses are construed to obtain the perception threshold. Unlike the method of constant stimuli, each stimulus trial in the transition method is presented only one time to a given number of observers; this method often includes 10 or more observers (Burro et al. 2011). Observer judgment responses in the transition method are then ranked based on the idea that, for every observer, there is only one corresponding threshold (Burro et al. 2011).

Randomisation of the judgment procedure is essential in the measurement of human perception thresholds to eliminate bias caused by *space* and *time* errors. Space error bias occurs when different human receptive areas are used (Gescheider 1997, pp. 51 - 52). Perceptual judgments are affected not only by differences between stimuli, but also by differences in perception between human receptive areas (Gescheider 1997, pp. 51 - 52). Time error bias, on the other hand, occurs when the perception trial judgments are presented to the observer successively (Gescheider 1997, pp. 51 - 52). Research has shown that the perception of one stimulus is more likely to be judged less intensely than the second, even if they both were identical (Gescheider 1997, pp. 51 - 52). Thus, it is crucial that trials be equally distributed between the different human receptive areas to eliminate space error bias and between judgement trials to eliminate time error bias.

2.2.2 Haptic Feedback

Haptic feedback, via haptic devices, is often used to replicate real world interactions through one or a combination of tactile and kinaesthetic feedbacks (Burdea and Coiffet 2003, p. 93). Feedback, such as vibrations and forces, experienced by the different parts of the human body are the result of programmed software algorithms. For instance, within limits such as the DoF and the workspace, a haptic feedback device can physically render the weight and softness feelings of a virtual object. The following sections will to review the haptic rendering process, a range of feedback devices, and different applications that use haptic feedback technology.

2.2.2.1 Haptic Rendering

Like all bodily functions, the human nervous system is central to everyday experience, from movement to sensory awareness. The skin's physical and behavioural functions help us feel things that could not otherwise be felt. Through tactile and kinaesthetic receptors, various perceptions can be distinguished. People use terms such as light, hard, rough, spongy, cold, heavy, rubbery, and tough to describe their tactile and kinaesthetic perceptions of the objects they experience.

Salisbury et al. (1995) defines *haptic rendering* as "the process of computing and generating forces in response to user interactions with virtual objects". This technique employs software algorithms to enable a user to touch, feel, and manipulate virtual objects through a haptic device (Basdogan and Srinivasan 2002). Burdea and Coiffet (2003, pp.125-126) note that this process of haptic rendering is made of three interlinked stages (see Figure 2.7). The first stage is the loading of the physical characteristics of the virtual objects (e.g., surface compliance, smoothness, weight) from a database. At this stage, collision detection is also performed to identify virtual objects that collide with each other when in contact.

The second stage of haptic rendering computes the collision forces based on various physical simulation models such as Hooke's law of elasticity (Burdea and Coiffet 2003, pp.125-126). Combining various physical simulation models can increase realism, but it can also add excessive load to computational resources whenever virtual objects are in contact. This stage also involves force smoothing and mapping. Force smoothing (also referred to as force shading) corrects the direction of the feedback in order to avoid sharp transitions when interacting polygonal surfaces. This correction results in smoothly curved shapes. Force mapping, on the other hand, applies the computed force to the specification of the particular haptic feedback device.

Haptic texturing, the last stage of haptic rendering, generates the tactile component of the simulation (e.g., vibrations and surface temperature) and sends it along with the computed force to the haptic output device. It is necessary to point out that the update frequency of the haptic rendering process should be at least 1 kHz in order to achieve a rich and effective interaction between the user and the haptic interface (Iglesias et al. 2008).

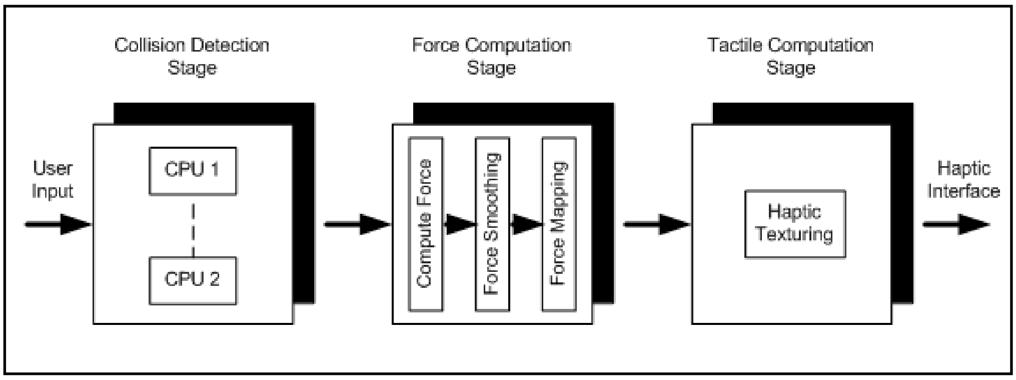

Figure 2.7: The stages of haptic rendering.

2.2.2.2 Weight Force and Surface Texture Rendering

Haptic weight rendering takes place at the second stage, where forces are computed, as shown in Figure 2.7. Weight perception is an important aspect of object examination that reflects the object's density and structure (Lederman and Klatzky 2009). The study of object weight force exploration has generally been approached from two different perspectives: passive and active (Lederman and Klatzky 2009). While passive exploration of an object takes place when it is placed in a still hand, active exploration involves lifting and moving the object. The latter approach has the advantage of enhancing the human ability to judge weight perception (Brodie and Ross 1984).

There are a number of illusions associated with human weight perception. A review by Lederman and Klatzky (2009) identified a number of illusions that affect the perception of weight including thermal, size and material illusions. Lederman and Klatzky (2009) conclude that "these variations in weight perception reflect a wide variety of mechanisms, ranging from low-level receptor responses all the way to high-level cognitive expectations."

It is necessary here to clarify exactly what is meant by the term *weight force*, which will be used in the discussion of the weight perception study described in Chapter 3. While an object's weight is measured in kg (or g), its force is measured in Newtons (N). Thus, an object weighing 1 kg in Earth's gravity is 9.81N (Ross and Brodie 1987). This study shall maintain the verbal distinction between weight and force, while using N to apply to both.

After weight rendering, texturing occurs at the third stage of the haptic rendering stages, as illustrated in Figure 2.7. The study of object surface texture exploration has also generally been approached from two different perspectives: first, by modelling friction as lateral forces on the nominal surface in a direction opposite to the haptic device probe motion, and second, by modelling texture as both lateral and normal forces generated in any direction (Siira and Pai 1996; Basdogan and Srinivasan 2002). The sensation of texture results from the effects of both a complex combination of bumps and cavity details, and friction on surfaces (Olsson et al. 1998). Friction, often associated with smoothness (Hollins et al. 2000), has been generally regarded as an important perceptual dimension of active touch (Smith and Scott 1996). Smooth materials such as glass, aluminium, plastic, nylon, Teflon, or silicone, which can be viewed as the building blocks of skin frictional properties (Smith and Scott 1996; Zhang and Mak 1999), are often used to make products like home furniture, accessories, and clothing.

Notwithstanding the fact that people normally examine surfaces using their bare fingers, a probe examination proved to be effective in discriminating between different types of surfaces (Klatzky and Lederman 1999; Tan et al. 2006). Probe friction is commonly modelled on stick-slip motion phenomenon. The “stick” state is due to a higher static coefficient of friction between surfaces, and the “slip” state is due to a lower dynamic coefficient of friction during the slip state itself (Mulliah et al. 2004). These coefficients allow any two surfaces to either stick to each other or slide over each other (Mulliah et al. 2004). Many commonly used friction models (e.g., Karnopp, Armstrong, and Dahl) depend on this idea of stick-slip, while others use algebraic equations or hybrid models that include events to address the increasing demand for realistic frictional surfaces (Olsson et al. 1998).

2.2.2.3 Haptic Feedback Devices

Haptic devices can be used to stimulate the human tactile and kinaesthetic senses by sending artificial sensations. They can be used to extend interactions with VEs by adding physical ambience. Today, users of haptic feedback devices are able not only to see, but also to “feel” and manipulate 2D and 3D virtual objects. There are a large number of haptic feedback devices with different interaction capabilities as a result of many years of effort in haptic technology development. Table 2.2 reviews commercial and research devices that provide variety of tactile and kinaesthetic sensations (Laycock and Day 2003; Benali-khoudja et al. 2004; Eid et al. 2007).

	Product	Description	Sensation	Year
Commercial Interfaces	Touch Master	Four vibration stimulators (each finger)	Tactile feedback	1993
	CyberTouch	Vibration stimulators: six (one on each finger, one on the palm)	Tactile feedback. Pulses or sustained vibration	1995
	FEELit	Haptic mouse	Tactile and kinaesthetic feedbacks sent via mouse pad.	1997
	CyberGrasp	Force-reflecting exoskeleton: five actuators, one for each finger	Resistive force feedback	1998
	iFeel	Vibrating mouse	Tactile feedback	2002
Research Interfaces	Temperature Display	Fingertip bed	Temperature feedback	1993
	HAPTAC	2D tactile display using index finger.	Tactile feedback. Electric pulses Shape Memory Alloy (SMA)	1993
	Prototype Tactile Shape Display	Two-fingered hand with two DOFs in each finger	Tactile feedback. Electric pulses Shape Memory Alloy (SMA)	1997
	Tractile Device	One stimulus, vibration.	Tactile feedback.	1999
	Lateral Skin Stretch	64 actuator/112 skin contactor/36 gap to create stress fields in the skin of the finger pad.	Tactile feedback.	2000
	Fingertip Stimulator	100 contactors. Waveform from each contactor.	Tactile feedback.	2001

Table 2.2: Overview of commercial and research haptic devices that have apperred of the years.

The future is not without such devices, though. Along with future haptic devices, Table 2.3 lists some of the common commercial haptic devices that are still used today, along with brief description of each. Mechanical haptic feedback devices such as the Phantom Omni developed by Sensible Technologies[6] and the Novint Falcon developed by Novint Technologies[7] provide rich and more immersive interaction in

[6] www.sensable.com [Last accessed 29 February 2012].

[7] www.novint.com [Last accessed 29 February 2012].

virtual space (see Figure 2.8). In addition to their reasonable size and cost, they offer great flexibility in terms of emulating tactile and kinaesthetic information and exploring objects in virtual environments. Intended for videogames, the Novint Falcon provides 3 DoF input capability and is capable of moving in all directions along the *xyz*-axes. The Falcon's closest rival, the Phantom Omni, provides 6 DoF input capability and is capable of moving with greater flexibility along the *xyz*-axes, as well as of rotation on each axis. This was intended for research on haptics, but it has also made it into commercial use, such as in medical training (Smith and Todd 2007; Coles et al. 2011).

Product	Description	Sensation	Cost (approx)	Year
SensAble Phantom Premium 3.0*	- Full arm movement. - Three DoF (can be extended to six DoF). - Workspace 838 W x 584 H x 406 D mm	Point based Tactile and kinaesthetic feedback	£38,000	1990s
SensAble Phantom Premium 1.5*	- Lower arm movement. - Three DoF (can be extended to six DoF). - Workspace 381 W x 267 H x 191 D mm		£37,000	
SensAble Phantom Omni Premium 1.0*	- Hand movement. - Three DoF (can be extended to six DoF). - Workspace 254 W x 178 H x 127 D mm		£13,000	
SensAble Phantom Desktop*	- Hand movement. - Six DoF - Workspace 160 W x 120 H x 120 D mm		£8,000	
SensAble Phantom Omni*	- Hand movement. - Six DoF - Workspace 160 W x 120 H x 70 D mm		£1,200	
Novint Falcon**	- Hand movement. - Three DoF - Workspace 101.6 W x 101.6 H x 101.6 D mm		£160	2006
Senseg E-Sense***	- Sends electro-vibration to the fingers. - Allows feeling textures, contours and edges. - Used on any touch interface device.	Tactile feedback	£???	Upcoming

Table 2.3: A list of commercially existing and future haptic devices. (*Price information was obtained from http://www.worldviz.com/purchase/pricelist.php [Last accessed 21/06/2012], while other device information was retrieved from http://www.sensable.com [Last accessed 21/06/2012]. **Device information was retrieved from http://www.novint.com [Last accessed 21/06/2012]. ***Device information was retrieved from http://www.senseg.com [Last accessed 21/06/2012]).

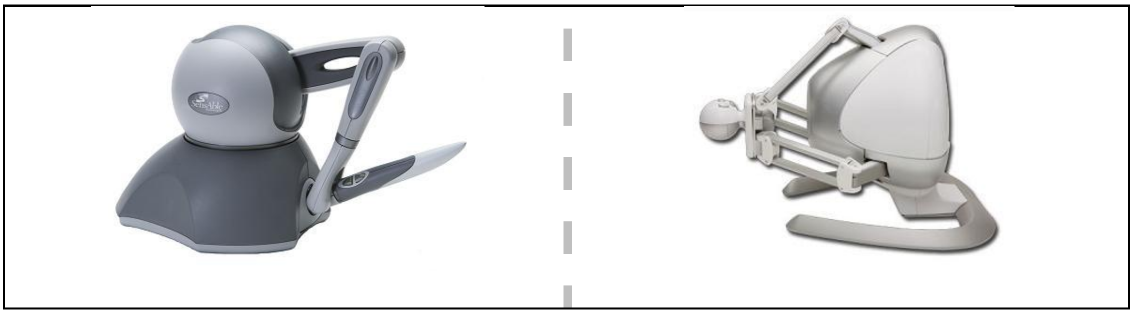

Figure 2.8: Left: Phantom Omni by Sensible Technologies (www.sensable.com). Right: Falcon by Novint Technologies (www.novint.com).

A more recent non-mechanical interactive haptic device is the E-Sense (see Figure 2.9) developed by Senseg[8]. Set to be commercialised around winter of 2012 or spring of 2013, the technology adds high fidelity tactile effects to touch-screens (Allan 2011). It does this by sending an electro-vibration stimulus using an ultra-thin durable coating on the touch interface that outputs various tactile effects (from textured surfaces and edges to vibrations and more) to the finger skin (Senseg n.d.). "Using Senseg technology, makers of tablet computers, smart phones, and any touch interface device can deliver revolutionary user experiences with high fidelity tactile sensations." as described by Senseg (n.d.).

Figure 2.9: E-Sense, a textured touch-screen by Senseg (www.senseg.com).

2.2.2.4 Haptic Applications

The applications for which haptic technology is useful are increasingly widespread. For instance, in combination with auditory and visual displays, haptic technology is used in medical and flight training (Eid et al. 2007; Saddik et al. 2011c). The virtual environments in these applications can be programmed to emulate real scenarios

[8] http://www.senseg.com [Last accessed 29 February 2012].

such as puncture training (see Figure 2.10) into the human body without endangering patients (Coles et al. 2011). Additionally, pilots are often trained in flight simulators, which apply forces on the controls that correspond to those that occur during actual flight (Stone et al. 2011).

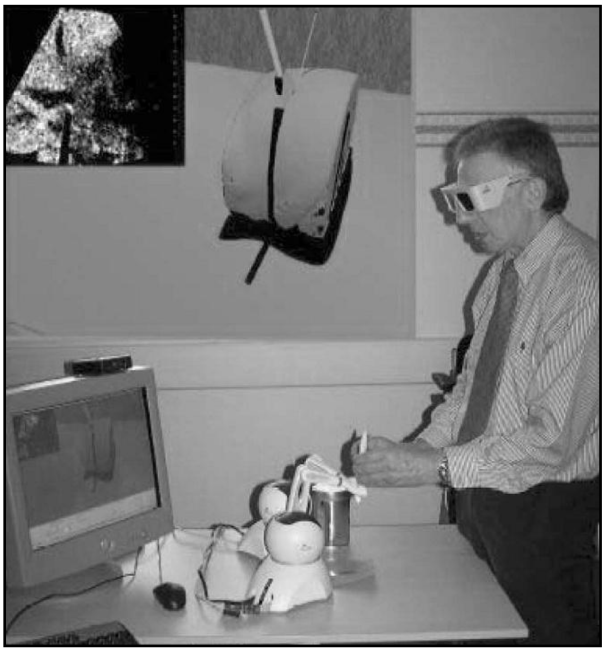

Figure 2.10: Ultrasound-guided needle puncture simulator using two Omni force feedback devices (Coles et al. 2011).

Nowadays, many types of applications use haptic feedback. Haptic technology is used, for instance, in entertainment and art applications (Eid et al. 2007; Saddik et al. 2011c). Videogame players can feel the physical properties of in-game objects, adding an extra level of interaction that traditional interface devices do not offer (Andrews et al. 2006). Paint artists can use painting programs with virtual brushes that give natural control of complex brush strokes, thereby, providing an artistic setting, that is equivalent to a real-world painting environment (Baxter et al. 2001; Sulaiman et al. 2010). Table 2.4 lists a range of recent haptic research to give an idea of the scope of the various application fields that haptic technology has touched.

Application	Description	References
Medical simulation and rehabilitation	Ultrasound-guided needle puncture simulator.	Stone et al. (2011)
	Training medical personnel on needle insertion and tissue cutting tasks.	Gonenc and Gurocak (2012)
	Rehabilitation programmes for stroke patients.	Ko et al. (2012)
Blind and visually impaired	Alert users of public transport systems when the desired stop is approaching.	Jacob et al. (2011)
	Helping blind children learn cursive handwriting	Plimmer et al. (2011)
	Aid visually impaired users with computer screen navigation and improve target selection.	Asque et al. (2012)
Education	Teaching students important concepts in introductory physics through haptics.	Hamza-Lup and Baird (2012)
	Help primary school pupils learning handwriting skills	Amin et al. (2011)
	Support secondary and undergraduate levels in the learning of key chemical concepts.	Davies et al. (2009)
Entertainment	Providing haptic feedback on the user's body while playing interactive games.	Israr et al. (2012)
	Enhancing the experience of movies and rides through surround haptics	Israr and Poupyrev (2010)
	Simulation of billiard ball striking that allows feeling the contact between cue and ball.	De-Paolis et al. (2008)
Arts and designs	Haptic based sketching interface to improve design creativity.	Rahimian and Ibrahim (2011)
	Enhancing the sense of being engaged and creative in artwork.	Sulaiman et al. (2010)
	3D shape modelling and deformation through natural hand gestures.	Pihuit et al. (2008)

Table 2.4: Haptic applications and research.

2.2.3 Haptic Challenges

In their survey on haptic-related research published in the past 11 years (January 2000–December 2010), Saddik et al. (2011b) found an increased interest in haptic studies within the research community (see Figure 2.11). While the community has taken significant steps towards solving many barriers, there are still many others in today's haptic technology, which prevents its widespread use in e-commerce (Eid et al. 2007). Foremost is the need for specialised devices for home use. Other barriers include difficulties in providing a network environment that eliminates jitter and latency of the transmitted haptic data to achieve real-time haptic interaction, providing a fast and affordable means of capturing complex haptic properties of real objects, and offering a wide range of simulated haptic properties, e.g., weight and/or surface texture.

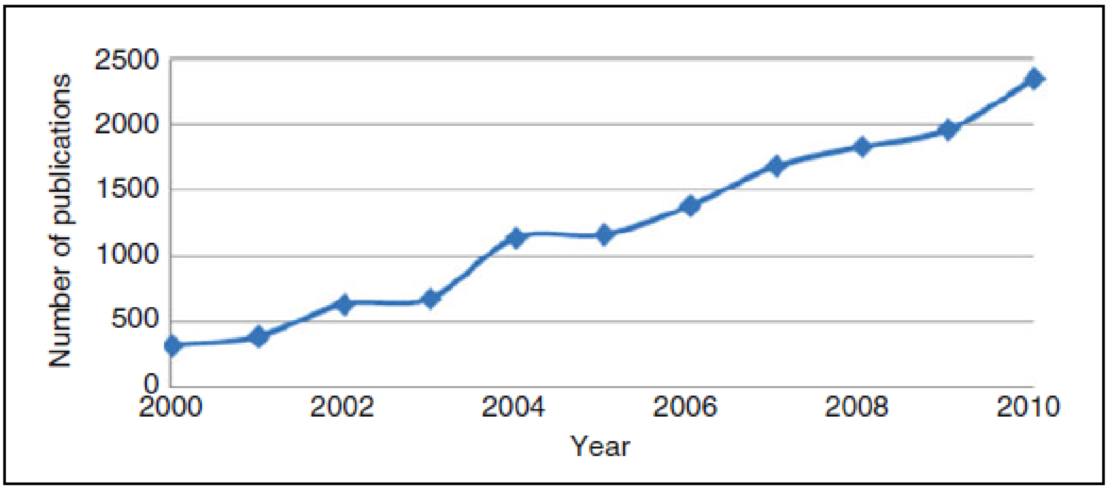

Figure 2.11: Haptic publications over the past 11 years (Saddik et al. 2011b).

Despite the barriers, the use of haptic feedback in online shopping is easily realisable since jitter and latency over networks associated with real-time interaction are not essential as haptic information can be rendered at the client side (Kammerl et al. 2011). However, the accuracy of haptically modelling various object properties is still a major issue. It is hoped that the increased involvement of haptic technology in the gaming industry (Morris et al. 2004; Davies et al. 2009) will lead to heavy investment in improving the technology and further increase the availability of affordable high-fidelity devices in consumers' homes. The following subsections will look at the key barriers to the effective use of haptic technology.

2.2.3.1 Cost of Devices

One of the major drawbacks is concerned with the fact that the cost of devices that produce such physical cues is relatively high. For example, a six DoF force-feedback device, such as the Phantom Desktop, costs around £8,000, and the Phantom Omni, the least expensive of the SensAble devices range, costs around £1,200 (see section 2.2.2.3). Although the Phantom Omni has made it into many commercial applications, it is still beyond the reach of the average home user. However, in 2006, Novint introduced a three-DoF haptic device, i.e., Falcon, which is intended for videogames and costs around £160. The device still offers great flexibility in terms of emulating tactile cues and exploring floating objects in virtual environment, and is far more advanced than the other alternatives: one/two-DoF devices, such as rumble-packs, the mouse, or the joystick. Such a low-cost haptic device can increase the turnout among potential home users and thus, increase its use in various applications beyond the gaming domain. Hence, the challenge here is to provide a high-fidelity haptic feedback device that is still cost-effective in order to make it both worth having and obtainable by the vast majority of home users.

2.2.3.2 Devices Limitations

Current haptic devices cannot generate haptic feedback for the whole body, but rather only for a part of the body, which restricts its applications (Brewster 2001). While such restrictions exist, haptic devices nonetheless play an important part in many applications (see section 2.2.2.4). However, haptic devices' capability to simulate haptic properties is still limited in terms of the range that the haptic devices can provide. Researchers have made many attempts to overcome these limitations using different techniques, by, for instance, adding auditory cues to enhance the simulation (McGee et al. 2001; Reyes-Lecuona and Cañadas-Quesada 2009) or even designing different haptic mechanisms (Choi et al. 2003; Mengoni et al. 2011). Indeed, providing a wide range of simulated haptic properties is a challenge that is likely to be overcome only through advances in haptic research and technology.

2.2.3.3 Haptic Modelling

Online shopping stores include a variety of products with a variety of haptic properties. Currently, the process of modelling products haptically requires a great deal of effort, as it involves knowledge in both graphic and haptic rendering techniques. It is time-consuming and cost-ineffective for businesses unless easier techniques are provided, such as laser or camera scanners (see Figure 2.12) to capture products effectively (Andrews and Lang 2007; Lang and Andrews 2011). The challenge here is to provide a faster and effective technique for capturing haptic properties of real objects that is easy and cost-effective for businesses.

Figure 2.12: Physical surface acquisition of real-world 3D objects (Andrews and Lang 2007).

2.2.3.4 Network Limitations

Effective haptic interaction through a virtual shopping environment, where consumers and salespeople interact haptically in real time, is still receiving a lot of attention. Current Internet technology suffers from network jitter and latency of the transmitted data, which makes consistent simulation of haptic data at a 1 KHz update rate, especially over large distances, a very problematic task (Glencross et al. 2007; Rosa Iglesias et al. 2008; Rakhsha and Constantinescu 2011). Such a difficulty renders the current network environment unsuitable for such interactions at the present time. Many studies suggest the use of peer-to-peer haptic interactions to overcome such problems, but whether this is an appropriate approach is still open to examination (Glencross et al. 2007; Khoury et al. 2007; Lee and Huang 2010). Therefore, the challenge here is to provide a network environment that eliminates jitter and latency of the transmitted haptic data. This requires a high refresh rate to achieve a rich interaction (Rosa Iglesias et al. 2008; Rakhsha and Constantinescu 2011).

2.2.3.5 Hardware Resources

A high-fidelity graphic and haptic representation is dependent upon the availability of computational resources (Hutchins et al. 2005). Such resources have a great effect on the richness of the interaction. A high volume of graphic and haptic processing may require the accessibility of new hardware resources to run smoothly on the client's side. Servers that host the processing may also require extra hardware resources to be capable of processing such a high volume of data. However, the vast majority of online consumers may not have the minimum hardware requirements to be able to run such technologies. Also, businesses may not be willing to spend resources to upgrade their current servers. Thus, the challenge here is to discover ways to run haptic feedback applications without the need for major hardware alterations to handle the required haptic interaction process.

2.2.3.6 Haptic Development

Haptic software development kits (SDKs) have been developed to help developers easily integrate the sense of touch into VR environments (Burdea 2000). Haptic SDKs are either extensions of existing VR libraries or stand-alone (Burdea 2000). In the first category falls the haptic extension of OpenHaptics SDK, developed by SensAble Technologies for the Phantom devices. The SDK is patterned after the open standards OpenGL, which is an API for developing interactive 2D and 3D graphics applications, which means it is familiar to graphics developers. Additionally, SenseGraphics[9] has introduced the H3D API SDK as a platform for multi-sensory applications. Like OpenHaptics, the H3D API SDK uses the open

[9] http://www.sensegraphics.com [Last accessed 29 May 2012].

standards OpenGL API, and it also takes care of both the haptic and graphic rendering. However, H3D API offers support not only to Phantom devices, but also to a wider range of commercial haptic feedback devices available today (e.g., Novint Falcon). It also enables rapid programming and design through simpler lines of codes. The challenge here, then, is to provide a haptic SDK that allows simple development of haptic environments and is capable of producing device-independent haptic applications.

2.3 E-Commerce

The growth of the Internet has opened up new avenues for businesses to trade their goods and services to global audiences. The ability to communicate with databases and to dynamically interact with Web applications has revolutionised the Internet from being a simple static publishing medium into a more sophisticated and efficient interactive medium that delivers a much richer and more effective user experience. Websites like Yahoo[10] and Google[11] have developed complex search engines to offer relevant information that satisfies each user's information need, while other commercial websites like Amazon[12] and eBay[13] have applied various techniques to adapt their goods and services content to the needs and preferences of individuals.

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[10] http://www.yahoo.com [Last accessed 29 May 2012].

[11] http://www.google.com [Last accessed 29 May 2012].

[12] http://www.amazon.com [Last accessed 29 May 2012].

[13] http://www.ebay.com [Last accessed 29 May 2012].

Alongside high street, many businesses consider an online presence an alternative shopping channel. In fact, some businesses, such as Dixons,[14], have abandoned the high-street presence due to a decline in sales (Tran 2006). The company has shifted to online shopping as a retailing medium in an effort to boost its revenue. Other companies, such as Amazon, have made huge revenues by investing largely in selling online products and services. Remarkably, regardless of the ongoing global economic meltdown (Elliott 2011), the American-based online retailer company's net sales reached a record high in 2011, with almost 50% of its revenue coming from outside North America (Hartung 2011).

Businesses spend a substantial amount of money on high-street store design to create pleasant shopping experience (Rohn 1998). Designing a usable and pleasant online shopping experience is as essential as having a pleasant high-street shopping experience. A usable and pleasant online shopping experience is known to significantly affect the user's shopping attitudes and behaviour in terms of purchase decisions and future online store revisits (Lee and Kozar 2011). Hence, online traders not only need to guarantee the availably of a wide range of product choices, but also ensure a highly satisfying delivery of the shopping experience to their customers.

The rapid growth of online sales has amplified the range of products and services available on the Internet (Meeker and Pearson 1997). E-commerce offers many advantages to both businesses and customers. Businesses can present their goods and

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[14] http://www.dixons.co.uk [Last accessed 29 May 2012].

services to millions of potential shoppers all over the globe, allowing them to browse, compare, check for availability at a convenient time, and have products delivered to a convenient location. This two-way commercial interaction experience over the Internet is commonly known as online shopping (Fan and Su 2011). In this experience, a website functions as a channel of interaction between shoppers and sellers which makes it very crucial to the success of the business. The following sections give a brief background on the Internet and e-commerce, with the goal of bringing a wider understanding of e-commerce, particularly in the online shopping context.

2.3.1 Background

In 1969, starting as a national defence research project, engineers at the University of California in Los Angeles (UCLA) and Stanford Research Institute (SRI) transmitted the first data on what was known as Arpanet (Ward 2009). In 1970, the name Internet was born, along with the idea of sharing information using different networks in different locations (Ward 2009). After that, the Internet continued to develop rapidly, but it was not until the mid 1980s that Internet-based products started to appear (Cerf 1993). In the 1990s, the US defence department made the Internet publicly available, and since then, private individuals and businesses have been able to join the Internet without prior request (Law 2004). Commercial services began to emerge as U.S. commercial email carriers linked their service to the Internet and many others around the world began to follow suit (Cerf 1993).

By the end of the 1990s, the number of Internet users began to grow at staggering pace, at around 20–50 percent per year (Coffman and Odlyzko 1998), and it is estimated to exceed 3 billion users worldwide by 2015 (Prnewswire 2011). In a recent report by the German Internet Exchange point DE-CIX in Frankfurt, between 2008 and 2010, Internet traffic grew from 200 GBit/s to 900 GBit/s, and this increase in traffic is expected to grow by a factor of 20 until 2015 (Dreschmann et al. 2011). This steady growth has encouraged many organisations and businesses to join the dotCom revolution. E-commerce sales estimates are growing quickly (see Figure 2.13). The US Census Bureau of the Department of Commerce reported that the estimate of U.S. e-commerce sales for the third quarter of 2011 was US$48.2 billion, an increase of 13.7 percent from the same quarter a year ago (Winters et al. 2011).

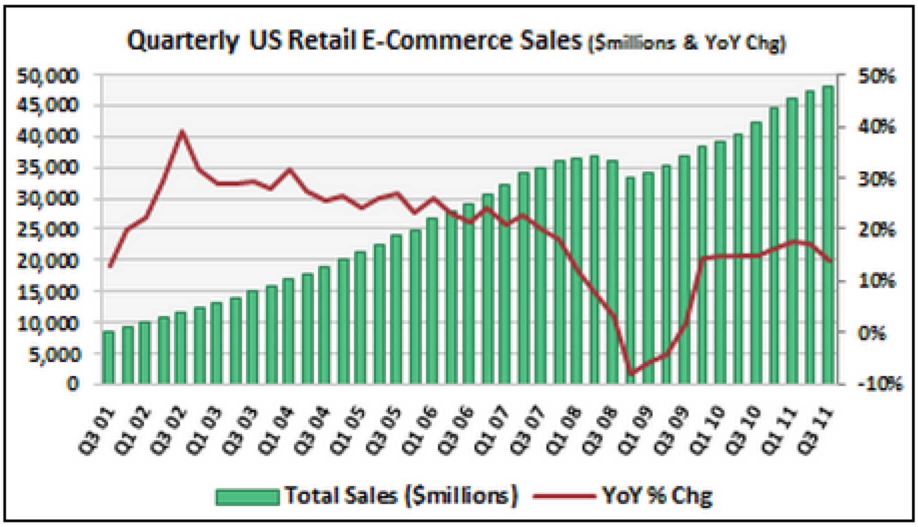

Figure 2.13:Quarterly Retail E-Commerce Sales (Retailsails 2011).

2.3.2 Market Categories

Although there are a number of e-commerce market categories (Barzilai-Nahon and Scholl 2007; Jovarauskienė and Pilinkienė 2009; Garigliano et al. 2011), literature in the field revolves around three fundamental entities that make up the e-commerce transactions exchange: businesses, consumers, and governments. Figure 2.14

categorises this transactions exchange between entities into five categories: business-to-business, business-to-consumer, consumer-to-consumer, government-to-business, and government-to-consumer. Of these five, business-to-business, business-to-consumer, and consumer-to-consumer are the most commonly used e-commerce exchanges (Jovarauskienė and Pilinkienė 2009).

As its name suggests, business-to-business e-commerce, also known as B2B, is about transactions that occur between companies. It is “an inter-organizational information system providing a virtual space where multiple buyers and sellers can communicate (e.g. exchange information on products/services offerings, either generic ones required across industries or industry-specific ones, and their prices) and transact (e.g. sell and buy products/services and pay for them), very often supported by various additional required services (e.g. financial, transport, logistic, etc.) as well” (Loukis et al. 2011). B2B e-commerce is by far the most influential of the e-commerce market categories. According to a statistical report published in May 2011 by the US Census Bureau (Census 2011), B2B e-commerce accounted for 91 percent of all e-commerce transactions.

Figure 2.14: Categories of e-commerce markets.

The second most commonly used transactions exchange is business-to-consumer e-commerce, also known as B2C. This refers to transactions that occur between a company and potential consumers over the Internet. Amazon's online store is a clear example of such an exchange. The online store offers an extensive catalogue of various goods, from inexpensive goods, such as toys, to very expensive goods, such as jewellery, and it allows consumers to order, pay for, and receive future services. B2C e-commerce global sales are growing rapidly, and this growth is expected to increase by an estimation of 58–75 percent in 2013 when compared to 2010 sales (Prnewswire 2011).

Another transactions exchange practised between consumers themselves over the Internet is the consumer-to-consumer e-commerce, or C2C. An example of such trade can be realised in online auction websites like eBay, where consumers place bids and buy products provided by other consumers. With over 114 million registered users looking for bargains and 1.3 million sellers selling a selection of unwanted goods, such as events tickets, mobile phones, and cars (Chua 2011), the demand for this kind of trading is evident. However, concerns over trust between buyers and sellers are still a major issue in C2C e-commerce (Liao and Weinan 2011).

The final two e-commerce market categories, government-to-business, or G2B, and government-to-consumer, or G2C, describe the exchange practised between the government and both companies and consumers over the Internet. Although the role of G2B and G2C is not of a business nature, but rather to ensure efficient service capabilities, they help directly in the development of e-commerce (Barzilai-Nahon and Scholl 2007; Huang 2010). Using innovative information technologies, where, for example, juridical acts, income taxes, registration of vehicles, realisation of health security, education programs, and other relevant information for companies and consumers are electronically available, has been found to be critically important for the success of e-commerce (Barzilai-Nahon and Scholl 2007; Jovarauskienė and Pilinkienė 2009; Huang 2010).

2.3.3 Potential Benefits and Challenges

E-commerce can offer many highly beneficial possibilities, therefore it is worthwhile to point out its benefits to businesses. These include reaching a global market, saving costs and time, product personalisation, and more effective automated processing of transactions. These benefits are briefly described below (Wendler and Shi 2001):

- **Global market**: a good e-commerce site can reach a wide base of consumers worldwide from a variety of cultural or ethnical backgrounds
- **Cost-saving**: paperless business transactions can reduce the costs associated with everyday business paperwork.
- **Time-saving**: since e-commerce is available 24 hour and 7 days a week, consumers can place an order at a convenient time and place.
- **Allow customisation**: when this is offered, consumers can order products that are tailored specifically to their needs or desires.
- **Simpler business**: minimal steps are needed to complete various business transactions that normally require various approvals.
- **Staff reduction**: processes such as products checking and tracking as well as credit checking are all automated.
- **Fewer errors:** there are fewer human errors due the automation of the transaction processes.
- **Information availability**: consumers' purchasing habits can be used to promote future products.

However, despite its many benefits, e-commerce still faces challenges that pose constraints and prospects that act as factors in the successful and sustainable implementation of a B2C e-commerce system. These challenges, which are both technical and non-technical, are detailed below (Khan and Martin 2011):

- **Security**: security issues pose an obstacles for most companies. Despite the security measures currently in place, online fraud still exists. Many consumers feel at risk when shopping online and are hesitant to provide their credit card information.

- **Reliability**: providing a reliable system is as important as providing a secure one. For instance, having low transmission capacity can result in an increased likelihood of missing an important business opportunity due to insufficient bandwidth.
- **Hardware and software compatibilities**: with the rapid development of new hardware and software, existing hardware and software components may not integrate well with new e-commerce solutions.
- **Costs and maintenance**: investing on building an e-commerce solution can be expensive due to, for instance, incompatibility with legacy systems. Also, with the rapid development of technologies, extra regular investments are needed to keep up to date.
- **Investment pressure**: companies are relentlessly under pressure to hastily invest in e-commerce solutions. However, in the absence of a comprehensive cost–benefit analysis, it is not clear whether current resources can cope with the new demands.
- **Real interactions**: current e-commerce websites are limited in terms of the consumers' ability to evaluate products, which may affect their confidence in the chosen products.

While many challenges exist, the lack of real interactions, where consumers can "feel and touch" products, is likely to pose a significant barrier to the continued growth of e-commerce (Childers et al. 2001). Consumers' value the ability to evaluate products using their hands, but current e-commerce applications fail to offer such an advantage (Hwang et al. 2006). Hence, this research intends to tackle this issue by integrating haptic feedback into e-commerce applications. The aim is to provide a highly interactive shopping experience in which shoppers can physically try products before buying them. The practical advantage of such an improvement is quite important to the success of the online business usability. However, the usability of providing haptic product information in e-commerce remains unknown.

2.4 Usability

The past several decades have witnessed a tremendous growth and greater dependence on e-commerce. Consequently, determining what enhances shopping experience for online consumers has become increasingly important for businesses attempting to meet customer expectations and stay competitive.

The terms *usability* and *user experience* have been used extensively in the literature, not only interchangeably, but also to mean different things (Hornbæk 2006; Bevan 2009; Roto et al. 2009). One of the most widely used definitions of usability and user experience is given by the International Standardisation Organisation (ISO) [15]. According to ISO, usability is defined as the “extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.” In contrast, the ISO defines user experience as the “person's perceptions and responses that result from the use or anticipated use of a product, system or service.” While both definitions focus on the experience of the use of a system, product, or service, the usability definition appears to have a broader context than the user experience definition.

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[15] http://www.iso.org [Last accessed 04 July 2012].

In fact, usability, by definition, already caters to the user's "perceptions and responses" towards a system, product, or service by measuring subjective satisfaction, as well as objective user performance measures (i.e., effectiveness and efficiency) (Bevan 2009). On the other hand, "objective measures such as task execution time and the number of clicks or errors are not valid measures for user experience" (Roto et al. 2009). Subjective measures such as user's expectations have more of an effect on the experience of the use of a system, product, or service than objective measures, according to Roto et al. (2009). However, Hornbæk (2006) argues that while the distinction between subjective and objective measures is, to some extent, hard to classify, studying both measures is essential, as each may lead to different conclusions regarding the experience. Hence, this study will use both terms interchangeably to take into account both subjective satisfaction experience (i.e., user experience) and objective performance experience.

2.4.1 The Importance of Usability

In the real world, B2C interactions are mainly based on a face-to-face approach. However, B2C interactions in an e-commerce setting are commonly done through a website, so its usability is central to the success of the business (Calisir et al. 2010). Nielsen (1993, pp. 24 - 25) places the concept of usability as a system acceptability requirement among other attributes such as cost and functionality that determines whether people will accept the use of a computerised system. Nielsen (2004) notes, "If you run an online business, you're in the user experience business: all the value flows through a user interface. It's essential to develop the expertise to interpret user research and an understanding of when to run usability studies. This is true even if you're not a usability specialist yourself and never want to personally run a study.

You still have to know how to deal with the reports and make the research findings relevant to your business."

In today's e-commerce, having a usable website is a prerequisite for the business's survival on the Web (Musaa et al. 2006). Usability also influences trust on e-commerce websites (Flavián et al. 2006a; Flavián et al. 2006b; Casaló et al. 2011). Trust, as defined by Flavián et al. (2006a), is "a group of beliefs held by a person derived from his or her perceptions about certain attributes; in marketing this involves the brand, products or services, salespeople, and the establishment where the products or services are bought and sold." Online customers value a website that they trust over any other attribute, such as cheaper price or the availability of a wider selection of products (Reichheld and Schefter 2000). Lack of trust is one of main contributors to customers' turning away from an e-commerce website in favour of more traditional methods of purchasing goods and services (Lee and Turban 2001; Cyr 2011).

Building trust builds loyal customers, which, in turn, increases the competitive power of e-commerce. Reichheld and Schefter (2000) argue that loyalty is "about earning the trust of the right kinds of customers—customers for whom you can deliver such a consistently superior experience that they will want to do their business with you." As consumers' trust develops over time, the business often becomes more profitable, too, as loyalty is developed (see Figure 2.15). Loyal consumers make repeated purchases and spread positive word of mouth, which helps increase the business sales and profit margin (Srinivasan et al. 2002). Heskett et al. (1994) claims that with 20 percent of total customers who are truly loyal, a company can tackle losses that result from doing business with less loyal customers. With this in mind, usability needs to be a major concern of any business on the Internet. In the context of B2C, there are several dimensions of usability that are integral to the success of e-commerce. These are discussed in the next section.

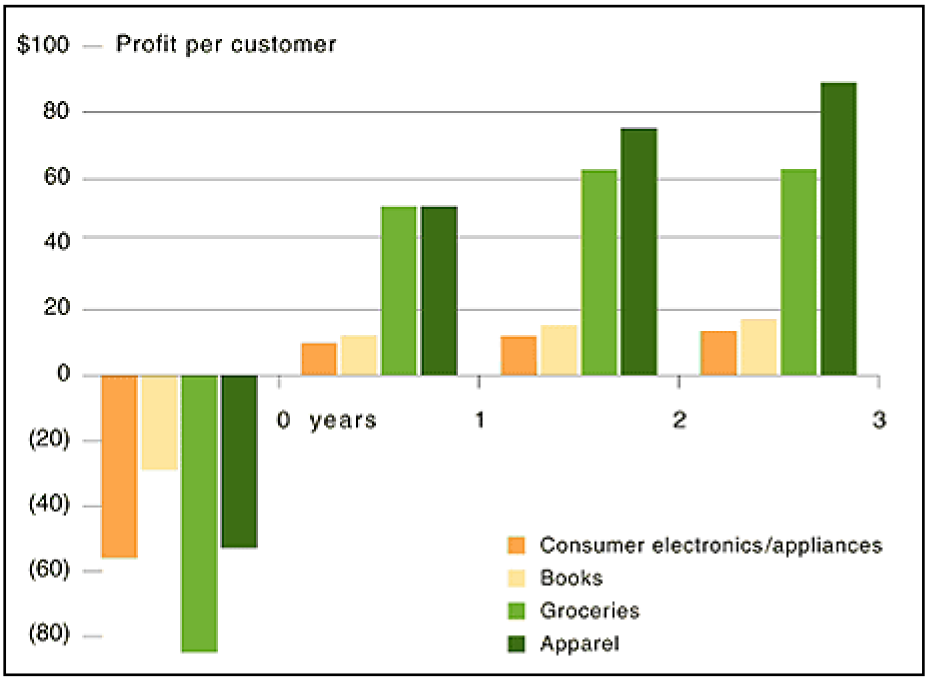

Figure 2.15: Customer life-cycle economics in e-commerce (Reichheld and Schefter 2000).

2.4.2 Usability Dimensions in E-Commerce

The usability of the e-commerce web site can have a great impact on the satisfactory experience of online shopping (Rigas and Alotaibi 2008). According to related literature reviews (Kim et al. 2003; Merwe and Bekker 2003; Machado and Reis 2006), e-commerce website usability can be related to five commonly recognised dimensions: interface, navigation, content, reliability, and technical aspects (see Figure 2.16). In what follows, these dimensions are briefly introduced, and examples are offered.

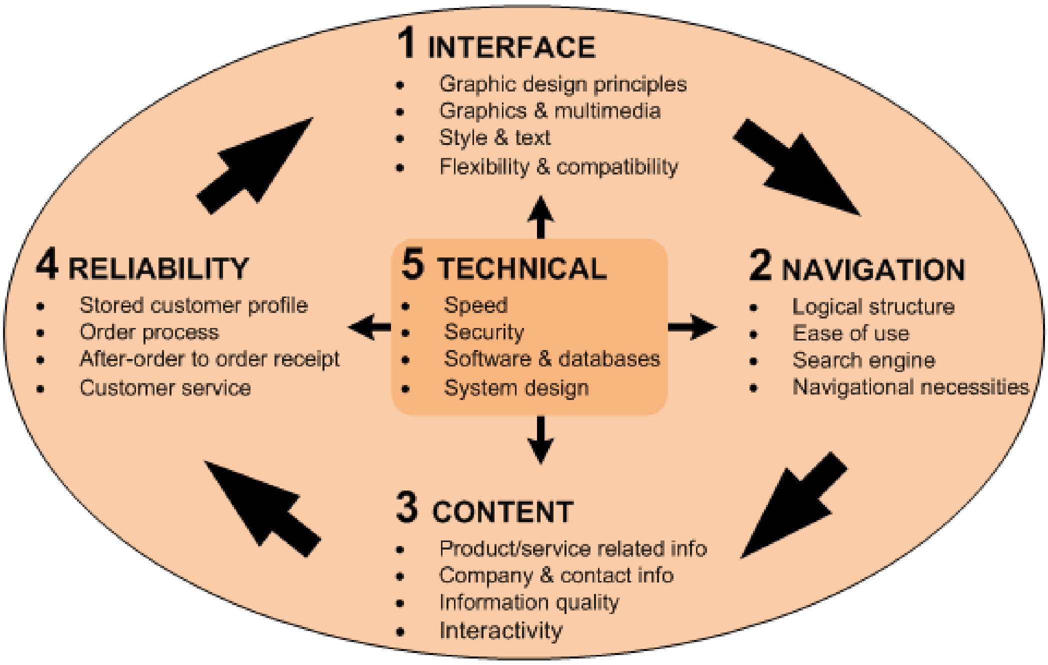

Figure 2.16: Usability dimensions for e-commerce websites (Merwe and Bekker 2003).

Interface: The e-commerce website interface is the first thing potential consumers interact with. Every time consumers interact with the website counts as an experience, and every experience is an opportunity for the business to delight consumers and make a good impression. This usability dimension has to do with the visual appearance of the website in terms of the backgrounds, fonts, colours, graphics, and layout, for example. A considerable amount of literature has been published on the interface visual appearance, and much of it has suggested various guidelines for Web designers (Strain and Berry 1996; Berkman 1997; Boyarski et al. 1998; Cai and Xu 2011; Westerman et al. 2011). Berkman (1997) and Strain and Berry (1996) suggest using a consistent layout so people know when they are at the desired website and when they have left it. Visual appearance can enhance the consumers' shopping experience (Cai and Xu 2011) and can play an definitive role in consumers' decision-making (Westerman et al. 2011).

Navigation: Once consumers reach an e-commerce website to purchase a product or service, they need to be able to easily explore the various pages and search for the desired products or services. During this process, navigation and search aids constitute an important part of the experience. In a study on user frustration in web navigation, Lazar et al. (2003) found that a disorganised and confusing navigation structure can push users to make many errors, and this can lead to increased user frustration. Such frustration can be avoided by providing an effective search and linkage structure that reduces the number of steps needed to locate the desired products or services (Shneiderman 1997). Nielsen (2001) argued that most users give up searching if their first attempt fails to find their desired product or service. Pearson et al. (2007), in their review of navigation literature, found that website usability is greatly influenced by navigation, and the lack of a good navigation structure can lead to cognitive overload.

Content: The quality of the content is critical for an e-commerce website. Providing rich and related information content can improve the consumers' shopping experience. Typical users retain only 10 percent of what they read, 30 percent of what they see, and 90 percent of what they act on (Rogers 2011). Hence, providing an excessive amount of information about the products and services is rather useless. One way to avoid excessive content is present the right information to the right people. Personalisation and customisation of content can reduce information overload and improve the interaction, increasing both satisfaction and sales by providing products and services that are tailored to each individual consumer (Perugini and Ramakrishnan 2003; Braynov 2004). Alternatively, in a study on social presence through the website, Hassanein and Head (2007) found that using socially rich descriptions and images of products (i.e., descriptions aimed at evoking positive emotions and views of products being worn by people in emotional settings) can result in more favourable attitudes towards the e-commerce website. Pan et al. (2004) notes that 3D visualisation, where consumers can see different angles of the products, provides rich information and enhances the experience through interactive media.

Reliability: After going through the website interface, navigating the pages, and exploring its content, consumers need an effective order fulfilment and payment handling processes. All e-commerce websites provide consumers with an online ordering facility, but the process of ordering can differ from site to site. While many e-commerce websites offer an immediate online order mechanism using a shopping basket where consumers can place products they want to purchase in a way that resembles a real-world shopping experience, others require more time-consuming mechanisms that involve filling out a form, emailing, or faxing communications to confirm and process credit card information (Zhao and Dholakia 2009). Amazon, for instance, stores consumers' information (e.g., address, credit card) in order to allow for a "one-click" purchase process to encourage repeated purchases (Zhao and Dholakia 2009). Effective order fulfilment and payment-handling processes, including easy ordering, easy payment, and easy cancellation, can attract more customers to purchase from the e-commerce website (Tsai et al. 2011).

Technical: This usability dimension is central to all other dimensions. It assures that the e-commerce website has utilised techniques and technologies to tackle aspects such as enabling fast and secure user experience throughout the shopping process.

For example, excessive use of multimedia content can have a considerable affect on speed of loading the web site content and can also slow down navigation. Lazar et al. (2003) have argued that frustrating experiences caused by long download times carry nearly half of the time spent in front of computers. Palmer (2002) has showed that the speed of web site access can significantly influence its usability. Furthermore, providing secure commercial transactions is another crucial step in the design of e-commerce web sites. For example, using secure protocols, such as Hypertext Transfer Protocol Secure (HTTPS), to encrypt communications and to enforce secure online payment gateway can strongly encourage customers to shop online. However, lack of security measures can increase perception of risk involved in shopping online which in turn can prevent people handing out their sensitive data (Muthaiyah et al. 2011).

2.4.3 Current Trends in E-Commerce Content Design

This section describes several design traits that are currently practised by website designers to enhance the consumer information experience in e-commerce in order to remain competitive (Najjar 2011). These design traits, described below, include online social media, automated recommendations and dynamic customisation, and virtual simulation.

Online social media: Social media networks, as defined by Boyd and Ellison (2008), are Web-based services that allow individuals to “(1) construct a public or semi-public profile within a bounded system, (2) articulate a list of other users with whom they share a connection, and (3) view and traverse their list of connections and those made by others within the system." Social media networks like Facebook,[16] MySpace,[17] and YouTube[18] have attracted millions of people by allowing them to keep in contact with other users (Pallis et al. 2011). They all share a common ground of allowing people to present themselves, but with different levels of social and media interaction capabilities. Some websites offer picture- or video-sharing capabilities, while others have built-in blogging and instant messaging technology (Boyd and Ellison 2008).

The rapid growth in the use of social networks has attracted many businesses to such networks for marketing purposes. In 2006, MySpace's "Shopping and Classifieds" sub-category, where music, ticketing, apparel and accessories, auctions, and videogames are located, received the largest share of visits, which reflects the interests of MySpace users (Prescott 2006). In that same year, in order to catch up with the ever-growing demand for social media networking as a business strategy, BBC (2006) announced that Google had paid £883 million for YouTube. Five years later, Google launched its brand new social media network (i.e., Google+), which was estimated to cost around £381 million in software development, according to Upbin (2011).

Google uses YouTube and Google+ to advertise products and services to targeted users. Sellers on websites such as eBay can place a YouTube media link within an

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[16] www.facebook.com [Last accessed 29 February 2012].

[17] www.myspace.com [Last accessed 29 February 2012].

[18] www.youtube.com [Last accessed 29 February 2012].

item description to make the item more desirable to buyers, or to demonstrate how an item works or how it can be used most effectively. Ebay also allows users to share an item they "like" among Facebook friends, which can attract more consumers.

Social networking has made a significant impact on how Internet users communicate, search for, and share data today. Such a feature, in a way, is changing e-commerce and helping move it in new directions. It has been argued that those who engage in social media networking obtain significant benefits in the form of increased trust between transaction partners and higher user satisfaction (Gayatri et al. 2008). Clearly, social networking is having an increasing impact on online business.

Automated recommendations and dynamic customisations: these can create many benefits for online consumers, including better preference matching, better products, better service, better communication, and a better experience (Vesanen 2007). Automated recommendations refer to the delivery of adaptive content, such as links, offers, advertisements, product descriptions, and product recommendations, that is suited to the needs or tastes of individual users or a group of users, based upon their personal and preference information (Al-Omar and Rigas 2008, 2009; Thongpapanl and Ashraf 2011). Automated recommendations involve a systematic process of collecting, classifying, and analysing Web data to display the desired content with minimal user intervention (Germanakos et al. 2005). This technique is widely used in various online systems, such as Amazon.com, where the system learns and recommends products based on the user's previous selections and on what other users have selected.

Dynamic customisations, on the other hand, allow the user to have more control over the content and decide on the desired product specifications (Al-Omar and Rigas 2008, 2009; Thongpapanl and Ashraf 2011). This technique is commonly utilised in various websites, such as Google and Dell[19]. Google.com allows users to customise their home pages according to their preferences without system intervention, while Dell goes further, allowing consumers to specify their desired system hardware/software before buying.

Given the availability of high-bandwidth Internet, NIKEiD[20] utilises technologies such as 3D rotation in an attempt to enhance the online shopping experience. For instance, this can provide shoppers with an image that they can manipulate, allowing them to zoom in on 3D views, rotate it for a 360° full-rotation view, and add to, delete from, or alter the elements of an image before ordering.

With respect to e-commerce, automated recommendations and dynamic customisations are a valued traits that can significantly increase sales by increasing consumer satisfaction (Jiang et al. 2010). It is believed that such techniques potentially influence the customer's favourable attitude toward the online shop, which eventually results in repeat buying behaviour (Srinivasan et al. 2002).

Virtual worlds: are artificial environments that provide the effect of immersion in an interactive computer-generated environment (Brey 2008). As such, the objective of

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[19] http:// www.dell.com [Accessed 29 February 2011].

[20] http:// www.nikeid.nike.com [Accessed 29 February 2011].

virtual worlds is to achieve a feeling of telepresence, immersion, and participation from a distance (Jäkälä and Pekkola 2007). Rapid enhancements in computer hardware and the availability of high-speed bandwidth have encouraged the use of such environments in various online applications. For example, Reuters has established a virtual headquarters in Second Life[21] to broadcast news related to both the virtual world and the real world, while BBC Radio has put on virtual events (Gajendra et al. 2011). Also, large companies such as Dell, Cisco, IBM, Microsoft, and Intel already have presence in Second Life, where they trade their products and services (Zhou et al. 2011).

As the name indicates, Second Life provides its users with a "second life" in which they explore, chat, shop, work, or even attend concerts using a virtual character. Many of these virtual activities, especially shopping, represent commerce opportunities. With a global revenue of US$5 billion in the year 2010, and estimated to rise to US$14 billion in 2012, virtual worlds certainly constitute an ideal place for businesses to operate (Kzero 2011). It has become an innovative platform for collaboration and business that bypasses traditional geographic constraints (Ondrejka 2007). Virtual interaction is much enjoyed and appreciated by users. These positive experiences can influence users' intentions to make repeated future visits (Stangl and Weismayer 2008).

[21] www.secondlife.com [Accessed 29 February 2011].

2.4.4 Usability Studies on Haptics

A wide variety of haptic applications has been studied in order to determine their impact on users' performance and experience. These applications cover a broad spectrum of themes, including but not limited to education and training, entertainment, industry and engineering, and marketing. Regardless of the haptic feedback technology utilised, previous studies have shown that providing haptic feedback has the potential to extend functionality and improve overall performance and user experience. Until now, despite its importance, haptic feedback has not yet made it to online shopping. A review of related studies is presented below.

In a gaming VE called "Ring on a Wire," Basdogan et al. (2000) examined the usability of haptic feedback with respect to time taken and subjective opinion regarding the sense of being together for the completion of collaborative tasks that involve touching and manipulating objects in shared environments. The study has shown that haptic feedback has noticeably enhanced users' performance and the sense of togetherness. A haptic audio virtual environment (HAVE) gaming environment aimed at blind and visually impaired people was developed by Wood et al. (2003). The virtual gaming environment enables users to manipulate and identify virtual objects using their sense of touch and audio feedback. The time users took to complete the game was recorded, but this was ignored at a later stage, as it was found to be a misleading measure. While a decrease in time might indicate a performance improvement, as users got better at the game, they started spending more time exploring the environment or different outcomes of play. However, the subjective experience findings that were reported suggest that such an environment provided ample opportunity for blind and visually impaired people to enjoy computer games.

Sener et al. (2002) evaluated the usability of a FreeForm haptic modelling system to virtually sculpt three-dimensional structures using tools and techniques similar to those that are employed by industrial designers in the real world. Industrial designers' opinions were questioned during the experiment, and they were also free to request further help from the evaluator. Evaluation results showed that haptic feedback, to a certain extent, supported industrial designers, especially during the early stages of design. However, the study suggested that the FreeForm on-screen modelling tools and functions were not constrained enough. Accurate control of the shape was not quite possible, which rendered the modelling tools and functions unsuitable for complex designs.

Bhatti et al. (2009) implemented a haptically enabled interactive and immersive virtual reality (HIVEx) training system to support the learning process of general assembly required by manufacturing industries. The training system provided a flexible, interactive training environment for performing assembly operations with physical restriction imposed by haptic feedback interaction. A user evaluation was conducted to assess the performance and user experience in terms of system ease of use and perceived level of understanding. The training system showed a satisfactory performance with respect to the time taken to complete all tasks. It provided the users with an easy–to-use experience for learning assembly operations and improved their overall ability to grasp the concepts involved.

Haptic technology has also been used in medical research to develop highly interactive training tools. Baillie et al. (2003) studied the performance of students trained using a Horse Ovary Palpation Simulator (HOPS) in ovary palpation compared to students trained using traditional anatomy lab methods. The comparison yielded no statistical performance difference, which suggests that haptic training is as effective at providing ovary palpation training as the traditional methods. Another medical haptic training was proposed by Crossan et al. (2003) to train veterinary students to examine the bovine reproductive tract by simulating the rectal palpation. Results indicated that students' performance improved as a result of the haptic training. Konukseven et al. (2010) developed and evaluated a visio-haptic dental training system using haptic and stereoscopic devices. The evaluation was conducted to measure dental students' performance and experience. The performance test results revealed that using the simulated dental system was comparable to using those found in clinic operations. Subjective experience questionnaire items were above average with regards to usability, clarity, effectiveness, help/support provided, and satisfaction.

Computer-based image editing and drawing applications represents another field that has benefited from haptic technology. Kagawa et al. (2010) proposed an image editing tool with haptic interaction to enhance user experience. Their study showed that haptic interaction in image editing has increased task time, but this increase in time shows a reduced number of cancelled operations when compared to the non-haptic image editing. User satisfaction questionnaire results showed increased image-editing usability and interest scores for the haptic system, but system ease of use and stress level scores showed similar user experiences.

Sulaiman et al. (2010) conducted another study to evaluate users' interactional experience of haptic sensation in drawing with two different interfaces. One replicated familiar drawing tools (e.g., pen and pencil), while the other used haptic sensation experience (e.g., stickiness and smoothness). The experimental results showed that users valued having control over the haptic sensation. While providing familiar drawing tools was considered more helpful, the haptic sensation experience was thought to better support creativity.

Jin (2011) investigated the use of a haptically simulated driving game to market motor vehicles and their impact on consumer behaviour. The game featured detailed models of cars and allowed for a haptic-assisted driving experience that included various road conditions (e.g., bumps, slides). Using experimental questionnaires, two environments were quantitatively compared, one with force feedback and one with no force feedback. Results revealed that consumers who required the use of touch information during a product evaluation held a more positive attitude when there were force feedback haptic stimuli, as opposed to when there was no force feedback.

A considerable amount of other publications describe the role of haptic technology on building more usable systems (Oakley et al. 2000; Oakley et al. 2001; Tahkapaa and Raisamo 2002; Yu and Brewster 2003; Yamaguchi et al. 2011). These studies have demonstrated that haptic technology is a promising way to achieve an interactively usable application and features.

However, despite its wide use in many applications, there has been little research conducted on using haptic feedback to enhance the usability of e-commerce applications. Among the limited number of prior haptic shopping-related studies, Shen et al. (2003) proposed a virtual showroom scenario, where a customer and a salesperson are presented as animated models, and the customer is able to perform various haptic-based interactions. However, their research aimed to develop a heterogeneous, scalable architecture for large collaborative haptics environments in which a number of potential users could participate with different kinds of haptic devices. Cha et al. (2005) mixed haptic interaction with 3D audio-visual contents in an Internet-based broadcasting system scenario for a home shopping channel in which viewers were asked to touch and manipulate products in real time. The authors did not implement the system, but rather demonstrated some potential application scenarios that would take advantage of the haptic interaction. More recently, Funahashi et al. (2009) implemented a touchable online shopping system that enables users to hold virtual objects in order to evaluate whether it is easy to measure the size and weight of virtual objects versus real objects. Despite favourable results, the study did not present broad details about the evaluation design. They also did not provide statistically significant evidence for any difference in performance or user satisfaction. Consequently, to the author’s knowledge, the present study is the first attempt to empirically evaluate the user experience of haptic interaction in an e-commerce context.

2.5 Chapter Summary

This literature review consists of three sections that consider different aspects of this research. The first section introduced haptics from different perspectives. It reviewed literature relevant to the human sensory system, and offered insight on how such sensory is measured psychophysically. It then reviewed haptic feedback technology in terms of the haptic rendering process, the haptic feedback devices, and the different applications that use haptic feedback technology. This section on haptics concluded with a review of the different challenges facing haptic technology. Among these challenges is the limitation of the haptic simulation imposed by the devices' limited simulation capability. As far as online shopping is concerned, such a limitation is not well understood. Hence, the first aim of this thesis is to psychophysically measure the human perception of haptic stimuli for an online shopping context. This measurement will provide JND thresholds, which can provide better understanding of this limitation on online shopping in terms of the availability of different stimuli to represent physical products.

A powerful medium for selling and purchasing products, e-commerce was then briefly introduced in the next section while given insights to historical background. After that, different market categories were discussed with a focus on the B2C e-commerce market category, where trades occur between a company and potential consumers over the Internet, in order to see where this work fits within the wider context of e-commerce market categories. Next, the section briefly introduced the potential benefits of e-commerce to businesses, along with its challenges. While there are many benefits, the online shopping experience is still hindered by the lack of physical product evaluation. Many consumers find it hard to compare online products to make more informed purchases (Hwang et al. 2006; Spence and Gallace 2011), which can deter them from engaging in the activity (Childers et al. 2001).

Haptic feedback can help provide physical evaluation during the shopping experience, but such an enhancement needs to be investigated through usability evaluation. Thus, the third and final section shed some light on the usability and user experience, and then highlighted the importance of usability in today's B2C e-commerce. The section then identified five usability dimensions that are integral to the success of online shopping websites, which demonstrate the place of this investigation within the larger context. Since this thesis seeks to enhance product information in online shopping, which is part of the third dimension (i.e., content), current trends in e-commerce content design were also explored to show its impact on online business. The section concluded with usability evaluations of haptic feedback on various applications, which showed its impact on users' performance and experience. However, haptic feedback as an enhancement to online shopping is still a relatively new option that needs to be examined. Hence, the second aim of this thesis is to investigate the use of haptic product information to enhance online shopping evaluation experience.

The importance of haptic simulation of weight and texture is easily seen in our regular shopping practice (e.g., rubbing fabrics to feel the softness, or lifting an iPod to feel the heaviness). Similarly, it can also be helpful when shopping online, just like visual and audio information. The idea of allowing users to feel objects through haptic feedback devices is still immature (Eid et al. 2007). Haptic feedback limitations exist; nonetheless, it may be feasible to circumvent these limitations by concentrating on providing an impression of the object in question that is sufficient to enable relative comparisons to be made. This might not be dissimilar to the sort of visual impressions available in existing online retailers. Despite obvious differences in the quality and availability of product images across e-commerce websites, these play an important role in catching the users' attention (Lee and Benbasat 2003) and generating positive attitudes amongst users (Hong et al. 2004).

The following chapters, i.e., Chapter 3 and 4, describe psychophysical studies of haptic weight and friction texture intended for addressing the first aim described above. These properties are believed to be fundamental to the shopping experience of many products that people may wish to shop for online. In light of the these studies, Chapter 5 describes an investigation to measure users' experience of using haptic product information to enhance online shopping evaluation in order to address the second aim of this thesis.

Chapter 3: Psychophysical Evaluation of Haptic Weight Discrimination

3.1 Introduction

Chapter 2 reviewed relevant literature in the haptic perception, e-commerce, and usability fields. This literature review revealed a number of knowledge gaps that form the basis for this study. In particular, it addressed the limitation of the haptic devices in terms of their simulation capacity. Previous work has looked at ways to improve such limitations through auditory cues (McGee et al. 2001; Reyes-Lecuona and Cañadas-Quesada 2009) or through designing different haptic mechanisms (Choi et al. 2003; Mengoni et al. 2011). However, in the context of online shopping, such limitations are not well understood.

This chapter presents a psychophysical investigation to measure the JND threshold (discussed in section 2.2.1.3) needed to effectively discern between two close haptic weight stimuli levels for an online shopping context using psychophysical methods of measurement (refer to Aim 1 in section 1.4). These thresholds can provide a better understanding of the limitations on online shopping in terms of the availability of different stimuli to represent physical products. The identification of the haptic weight force JND threshold is important to the primary investigation, where various representations of product weights are required, as will be discussed in Chapter 5.

3.2 Motivation

The work presented here focuses on one of the primary haptic properties needed to support haptic online shopping, namely that of reliable weight perception. There are a number of studies on JND thresholds for weight force for human subjects (Srinivasan and Basdogan 1997; Allin et al. 2002; Dominjon et al. 2005; Hinterseer et al. 2007), but there is a dearth of research on how this could be related to online shopping, in particular in environments where users' arms are not restricted.

In the nineteenth century, the German physiologist Ernst Weber reported 10 percent JND when measuring threshold in an experiment involving active lifting of physical weights on the hand and arm, as noted by Kramer (2010). Dominjon et al. (2005) observe that the visual motion of a manipulated virtual object can strongly decrease or increase the threshold needed to discriminate between the weights of objects, but they report 10 percent JND threshold when visual motion was congruent. Allin et al. (2002) also report a 10 percent JND threshold when applying haptic forces to the index finger. However, another experiment by Brewer et al. (2005) suggests a JND threshold of 19.7 percent for young subjects (ages 18-35) and 31.0 percent for elderly subjects (ages 61-80) when applying haptic forces to the index finger. Moreover, Srinivasan and Basdogan (1997) argue that the threshold of force discrimination must be 20 percent or above when squeezing two parallel aluminium plates with the thumb and forefinger. Hinterseer et al. (2007) describe a haptic prediction model based on human perception that is in the 5 to 15 percent range. These variations in threshold could be due to the techniques and technologies utilised in the particular studies, but such ambiguity is problematic when developing haptic support or when deciding which haptic technologies to adopt.

These threshold findings, while suggestive, cannot be incorporated into online shopping applications due to the constraints on the experimental setup. In a physical shopping environment, shoppers have the choice to hold and move objects unconstrained, depending on their physical strength and the nature of the object, as shoppers have physical contact with the actual object. It is likely that, based on current haptic technologies, online shoppers will be limited to discrete judgements of objects, one at a time. This will require that the presented objects of different weights be represented with a haptic rendering that provides weight differences that are reliably perceivable, for example when comparing two MP3 players, relative weights between the two players may be more important than the actual absolute weights.

Given the variations in JND thresholds found using different experimental techniques and technologies, there is a need for further investigation to support haptic-based shopping applications. This study explores JND threshold for a Phantom Omni haptic device using free exploration. Unlike other technologies, the Omni is relatively small in size and able to provide a variety of haptic interactions. If haptic-based shopping were to be adopted in the future, these advantages are likely to be among the characteristics of the ideal device.

3.3 Aims

The aim of this experiment was to examine the users' perceptions of simulated haptic weights in order to identify the smallest detectable difference. More precisely, the experiment attempts to identify the minimum JND threshold needed to distinguish between two simulated haptic weights across a range of different weights in an online shopping context.

3.4 Objectives

The objective of this study is to develop an experimental platform to allow users to interact with and compare simulated virtual weights. The platform allows for the judgment assessment of different combinations of virtual weights and also the recording of the contributed judgmental decision responses in order to achieve the addressed aim of the study.

3.5 Environment Design

The experimental environment was controlled using a Phantom Omni force feedback device to convey haptic weight forces. The device allows for virtual interactions in three-dimensional space with six degrees of freedom (DoF), namely *x*-, *y*-, and *z*-axes, and rotation around each of these axes. The force feedback device workspace is approximately 160mm (width) x 120mm (height) x 7.1mm (depth) and can generate up to 3.3 N, which is enough for the purpose of the experiments. The connection between the device and the computer is established via an IEEE 1394 (firewire) cable. The computer used to build the experimental environment consists of a laptop running Window XP on an Intel Core 2 Duo CPU at 1.66GHz with 504 MB of RAM, displayed on a 24-inch LCD monitor.

H3D API[22] is used to develop both the visual appearance and the haptic feedback interactions. The H3D API (version 2.0) is an open-source haptics software development platform that uses X3D and Python scripting language in one unified scene graph to handle both graphics and haptics. H3D API is written in C++ and uses

[22] http://www.h3dapi.org [Accessed 29 February 2011].

OpenGL engine to render the graphical representation, and Haptic API (HAPI) engine to render the haptic sensation (see Figure 3.1).

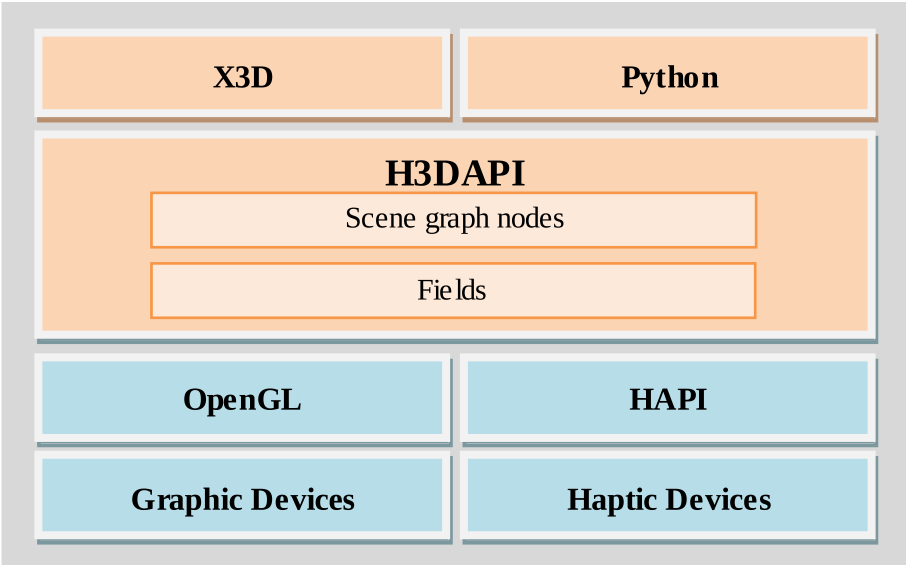

Figure 3.1: H3DAPI architecture (SenseGraphics[23])

H3D programming resembles X3D programming to a great extent, since both use the same code to describe the scene and store the codes in the same file extension (i.e., x3d). However, H3D platform has custom X3D nodes and fields for allowing the development of various haptic sensations. Hence, it is not a standard X3D file that can be run in ordinary X3D browsers. H3D uses an H3DViewer to allow X3D scenes to be loaded with or without the custom nodes and fields. Along with X3D, H3D uses Python scripting to handle various interaction behaviours, such as modifying the scene and performing events. It does this by routing the necessary H3D scene nodes and fields to an external Python file extension (i.e., .py). The use of X3D and Python in the H3D programming platform offer the advantage of allowing rapid haptic

[23] As illustrated in the H3DAPI datasheet http://www.sensegraphics.com/datasheet /H3DAPI_datasheet.pdf [Accessed 29 February 2012].

environment development. The following subsections will discuss the experimental environment design in more detail.

3.5.1 Experimental Environment

In order to investigate the differential threshold for haptic weight forces, an experimental environment consisting of virtual cubes was developed. Figure 3.2 shows the experimental environment developed to allow weight discrimination trials, expressed in Newton force, to be carried out according to the psychophysical measurement method of constant stimuli and the method of transitions (see section 2.2.1.3). The cubes were identical in shape and size to prevent any possible illusion (more on illusion in section 2.2.2.2), but each was assigned an identification letter to allow comparisons between the pair of virtual cubes. To ensure consistency, the cubes also have a small circle in the middle, which is used as a mark to indicate the holding position. When held using the haptic feedback device, the cubes provide the weight forces to the human hand. The cubes can be moved and abandoned anywhere in the virtual space. However, they return to their original middle position at the end of each trial. A trial counter at the top of the screen is updated each time a new pair of weights is evaluated.

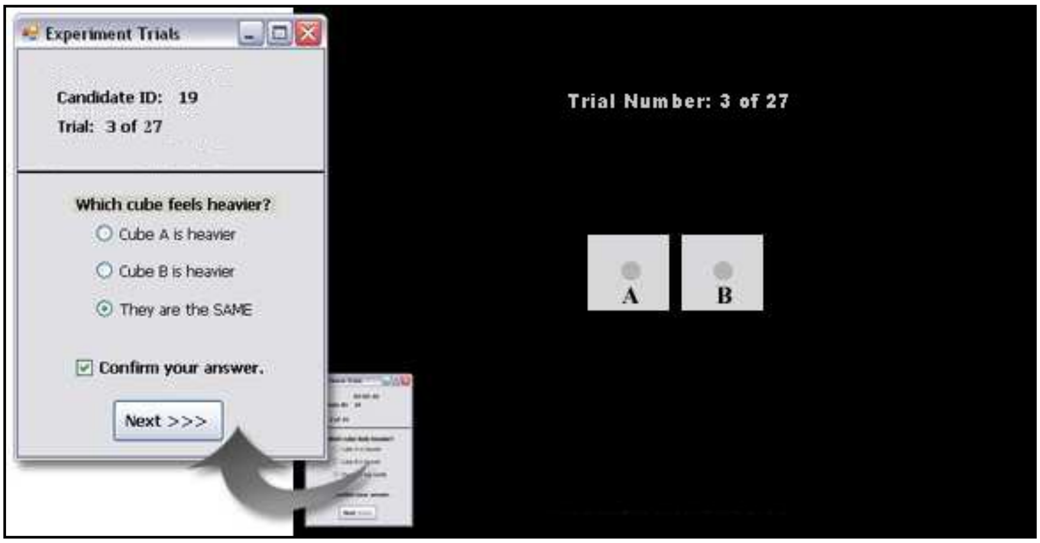

Figure 3.2: Visual output for the haptic weight discrimination experiment.

Newton force trial values representing different pair of weights (i.e., Cube A and Cube B) were stored in an Excel spreadsheet file for easy access and trial randomisation. Depending on the trial, the stored pair of force weights was obtained through Python scripting (see Figure 3.3) and routed to the X3D file (see Figure 3.4) to be assigned to the appropriate cube representation. Each cube representation had a separate custom *ForceField* node, provided by the H3D API. The nodes had an adjustable *force* field that allowed constant forces to be rendered along the *xyz* coordinates. For the purpose of this experiment, weight forces were rendered on the negative *y*-direction (see section 3.5.2).

Separate H3D API custom *SmoothSurface* nodes were also used for each cube. The nodes have adjustable *damping* and *stiffness* surface fields to adjust the velocity and the stiffness of the virtual surface respectively. While the *damping* surface field was defaulted to "0.0," the *stiffness* surface field was defaulted to "0.5." Such an arrangement was necessary to allow the surface of the virtual cubes to be touched by the haptic feedback device. However, when the cubes were held in the virtual space, python scripts adjusted the *stiffness* surface field to "0.0" in order to eliminate interference with the force weights applied by the *force* fields. The *stiffness* surface field values returned to their default value of "0.5" when the cubes were abandoned, since no weight forces were being applied at this point.

Perception judgments after each trial were obtained through a question that was displayed at the bottom left corner. The question form interface used Tkinter, a standard graphical user interface (GUI) library for Python, to provide user interface controls, such as command buttons, radio buttons, checkboxes, labels, and error messages. The question form interface recorded the judgment inputs and stored them in an Access database for later analysis. To make certain that the judgments inputted through the radio buttons were the ones intended by the user, a checkbox to confirm the judgment answer had to be ticked before clicking the "Next" button. If it was not ticked, the system would display a message asking the user to confirm their answer before they clicked "Next." However, if no radio buttons were selected, the system would display a message asking the user to select one answer before they clicked "Next." At the end of all of the trials, a "Thank you for participating in this experiment. Click OK to end the trials" message was displayed.

The development required the use of win32com Python package to communicate with COM-compliant programs. The Win32com package is part of Python Win32[24] extensions, which deliver Windows operating system-specific functionalities that are unavailable in Python scripting language. The package allows Python to access and

[24] http://python.net/crew/skippy/win32/Downloads.html [Accessed 29 February 2012].

execute various commands that are necessary to store and retrieve data in the Excel spreadsheet and the Access database files.

```
****Importing H3D and Python libraries.
…
…
from H3D import *
from H3DInterface import *
from Tkinter import *
from tkMessageBox import *
from win32com.client import Dispatch
from win32com import *

****Initialisation of environment variables.
…
…
file_name = 'C:\Force\weights.xls'
excel = Dispatch('Excel.Application')
engine = win32com.client.Dispatch("DAO.DBEngine.36")
database = r"\Force\results.mdb"

****Class WeightChangeA conveys weight forces to cube A.
…
…
class WeightChangeA( TypedField( SFVec3f,
                                        ( MFBool,         #  Cube A is touched.
                                          SFBool ) ) ):  # Button is pressed.

…
…
          while (TrialCount <= 27):
                excel = Dispatch('Excel.Application')
                excel.Visible   = False
                workbook        = excel.Workbooks.Open(file_name)
                workBook    = excel.ActiveWorkbook
                activeSheet = excel.ActiveSheet
                sheets      = workBook.Sheets
                sheet = sheets('Weights')
                sheet.Activate()
                sequence = sheet.Cells(TrailCount,4).Value
                weightA = sheet.Cells(sequence,1).Value
                excel.Visible = 0
                return Vec3f(0, float(weightA), 0)
          else:
                return Vec3f(0, 0, 0)
                excel.Quit()
                excel.Visible = 0
                del excel
…
…
```

Figure 3.3: Python Source code snippet example saved as a ".py" file. The code deals with various behaviours such as modifying the scene and performing events.

```
****Visual presentation of Cube A
…
…
      <MatrixTransform DEF="TR_A">
        <Transform translation="-0.05 0.03 -0.1">
          <Shape>
            <Appearance>
              <Material diffuseColor=".1 .1 .1" specularColor=".1 .1 .1"/>
              <ImageTexture DEF='imageA' url='"A.JPG"'/>
              <SmoothSurface DEF="SurfaceA"/>
            </Appearance>
            <Box DEF="BoxA" size="0.08 0.08 0.08">
…
…
            </Box>
          </Shape>
          <ForceField DEF="ForceA"/>
        </Transform>
      </MatrixTransform>

****Routing directories for Cube A
…
…
      <PythonScript DEF="PS_stiffnessA" url="StiffnessChange.py" />
…
…
      <PythonScript DEF="main" url="main.py"> </PythonScript>

****Routing fields to python scripts responsible for the stiffness of cube A. Stiffness is disabled only when the cube is touched and the haptic feedback device main button is clicked.
…
…
    <ROUTE fromNode="BoxA" fromField="isTouched"
           toNode="PS_stiffnessA" toField="StiffnessChange" />
    <ROUTE fromNode="HDEV" fromField="mainButton"
           toNode="PS_stiffnessA" toField="StiffnessChange" />
    <ROUTE fromNode="PS_stiffnessA" fromField="StiffnessChange"
           toNode="SurfaceA" toField="stiffness" />

****Routing fields to python scripts responsible for the weight of cube A. Weight is provided only when the cube is touched and the haptic feedback device main button is clicked.
…
…
    <ROUTE fromNode="BoxA" fromField="isTouched"
           toNode="main" toField="WeightChangeA" />
    <ROUTE fromNode="HDEV" fromField="mainButton"
           toNode="main" toField="WeightChangeA" />
    <ROUTE fromNode="main" fromField="WeightChangeA"
           toNode="ForceA" toField="force" />
…
…
```

Figure 3.4: H3D Source code snippet example saved as an ".x3d" file. The code deals with the graph scene and the haptic sensations.

3.5.2 Haptic Weight Forces

As discussed previously (section 3.5.1), experimental weight forces were stored in an Excel spreadsheet file and were displayed to the user using a haptic feedback device, which varied according to the trial. Haptic weights forces in the experimental environment were evaluated over three standard stimuli (1.2, 1.5, and 1.8) in order to examine different force magnitudes. More standard stimuli magnitudes were not possible at this stage, as the comparison stimuli needed for the evaluation may fall beyond the upper limit of the haptic device's capability (i.e. 3.3N) or may present no haptic weight stimuli if they are otherwise in the lower limit.

Each standard stimulus was compared to nine comparison stimuli: four incremental comparisons, four decremental comparisons, and one comparison to the standard stimulus itself. The incremental and decremental comparisons spreads are separated by equal distances, as illustrated in Table 3.1. Such spread coverage within the haptic feedback device capability is necessary so that the comparison stimulus of superior magnitude is always judged to be heavier than the standard stimulus, and the comparison stimulus of inferior magnitude is always judged to be lighter than the standard stimulus.

Standard Stimuli	Comparison Stimulus Values								
	← ←← Spread → → →								
	-80%	-60%	-40%	-20%	0%	20%	40%	60%	80%
-1.2	-0.24	-0.48	-0.72	-0.96	-1.2	-1.44	-1.68	-1.92	-2.16
-1.5	-0.3	-0.6	-0.9	-1.2	-1.5	-1.8	-2.1	-2.4	-2.7
-1.8	-0.36	-0.72	-1.08	-1.44	-1.8	-2.16	-2.52	-2.88	-3.24

Table 3.1: Newton forces value used in the weight discrimination experiment trials. Negative force values used to render downward forces along the y-axis.

Pairing the standard weight force stimulus with each of the comparison stimuli resulted in 27 experimental weight force trials, i.e., 9 x 3. Experimental trials are sequenced in a random order using a random number generator[25] with the standard stimulus used first for half of the trials and the comparison stimuli used first for the other half, to provide unbiased JND estimates (Gescheider 1997, pp. 50 - 54).

3.6 Experimental Method

The experiment was conducted as a within-subjects design. Subjects were randomly exposed to 27 randomly sequenced weight force trials; they were assigned one discrimination task to complete for each trial they were exposed to. All subjects were given a training session to familiarise them with the haptic environment. The training environment has an interface and a discrimination task identical to the actual experimental environment. However, unlike the experimental environment, the training session consisted of trials of six pairs of haptic weight forces with extremely large weight differences, which were repeated if necessary, to allow subjects to become familiar with the interface and the device.

3.6.1 Task

In order to evaluate the haptic weight forces, subjects were are asked to feel a pair of weight forces and rate their perceptions using three rating categories (Burro et al. 2011). As illustrated in Figure 3.2, for the question "Which cube feels heavier?" subjects were offered three possible answers:

- Cube A is heavier.
- Cube B is heavier.

[25] www.stattrek.com/Tables/Random.aspx [Accessed 20 January 2011].

- They are the SAME.

After they had confirmed their answers with a confirmation checkbox, they proceeded to the next evaluation trial until all 27 trials were completed.

3.6.2 Subjects

Opportunistic sampling was used to recruit subjects. The recruitment was achieved through emails and by placing posters around the university campus. A total of 24 subjects, aged 18 to 39, successfully participated in the experiment; 12 were female and 12 male. All were students at Durham University, from various faculties and degree programs. Twenty-two were self-reported right handed, two were ambidextrous, and all used their dominant hand with the haptic device. All subjects used a computer on a daily basis.

3.6.3 Procedure

After subjects were welcomed and guided to the lab by the experimenter, they were asked to take a seat in front of the computer, where they were verbally introduced to the purpose of the study. Upon agreement from the subjects, they were asked to sign a consent form. After brief handling instructions regarding the device and the training environment (see section 3.6), a short training session was then carried out. This was to make sure that the subjects had a basic understanding of how to operate the environment and perform the discrimination task before they were exposed to the experimental activities.

During both the training session and the experimental session activities, subjects were seated with their heads located approximately 60 cm from the centre of the screen. The stylus tip of the haptic feedback device was positioned to match arm length, ensuring that subjects were able to rest their elbows on the table. The device was manipulated with the dominant hand, while the other hand was used to enter answers on the screen using a regular PC mouse (see Figure 3.5).

Figure 3.5: Experimental setup for haptic weights.

Following the training session, the experimental session activities were started. Subjects were asked to complete an on-screen pre-questionnaire, which included demographic questions for future reference, and then they pressed the "Start" button to begin the actual experimental activities. They used the haptic device stylus to lift the pair of cubes and to make a perception judgment of their heaviness. To lift the cubes, subjects had to move the haptic pointer on the screen until it touched the grey circle on the surface of the desired cube, then press and hold the button found on the haptic stylus. They could lift the cubes as often as they liked, and they could also switch between them as often as they liked, to compare weight forces.

Once a judgmental perception was made, subjects could then select an appropriate answer that reflected their heaviness judgment for each trial using the mouse. They were presented with three choices to rate their perceptions, as described in section 3.6.1. Once a choice was selected, subjects had to confirm it and press the "Next" button to proceed to the next trial, and they continued to do so until they reached the end of all 27 trials. The complete session, including the training phase, lasted for 15-20 minutes. Ethic approval was granted by the School of Engineering and Computing Sciences Ethics Committee at Durham University.

3.7 Results

All 24 subjects successfully completed the experiment. The results for weight stimuli comparisons were computed for JND via the method of transition (see section 2.2.1.3). The resulting graphs representing the psychometric function with the proportion of heaviness probability distributions (y-axis) relative to the responses, starting from lowest to highest, plotted against values of the comparison stimuli (x-axis) are shown in Figure 3.6–3.8 (see Appendix A for subjects' responses).

The graphs display the proportion of times the standard weight stimulus, when paired with nine comparison weight stimuli, was reported as having a greater weight. The comparative judgment yielded a sigmoid curve, as a function of the difference in contrast between two stimuli. The proportion point of 0.50 on the psychometric function is known as the Point of Subjective Equality (PSE) (Gescheider 1997). This point represents a complete lack of discrimination, where the comparison weight stimulus is subjectively perceived as equal to the standard weight stimulus. The proportion points of 0.25 and 0.75 on the psychometric function were used to discover the weight JND threshold for each level of standard stimuli. The upper JND (JND^U) threshold is the stimulus ranging from PSE to the 0.75 proportion point, whereas the lower JND (JND^L) threshold is the stimulus ranging from PSE to the 0.25 proportion point. JND^U and JND^L were then averaged to give one JND threshold for the each stimuli level (Gescheider 1997). The JNDs and the corresponding Weber Fractions are summarised in Table 3.2.

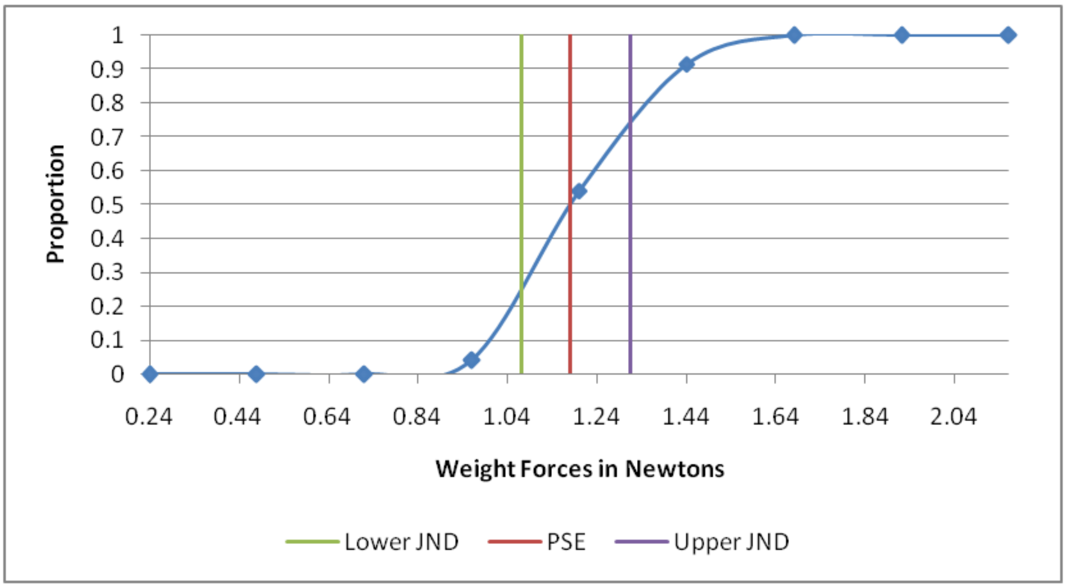

Figure 3.6: JND results for weight discrimination based on the 1.2 Newton force standard stimulus (summarised in Table 3.2).

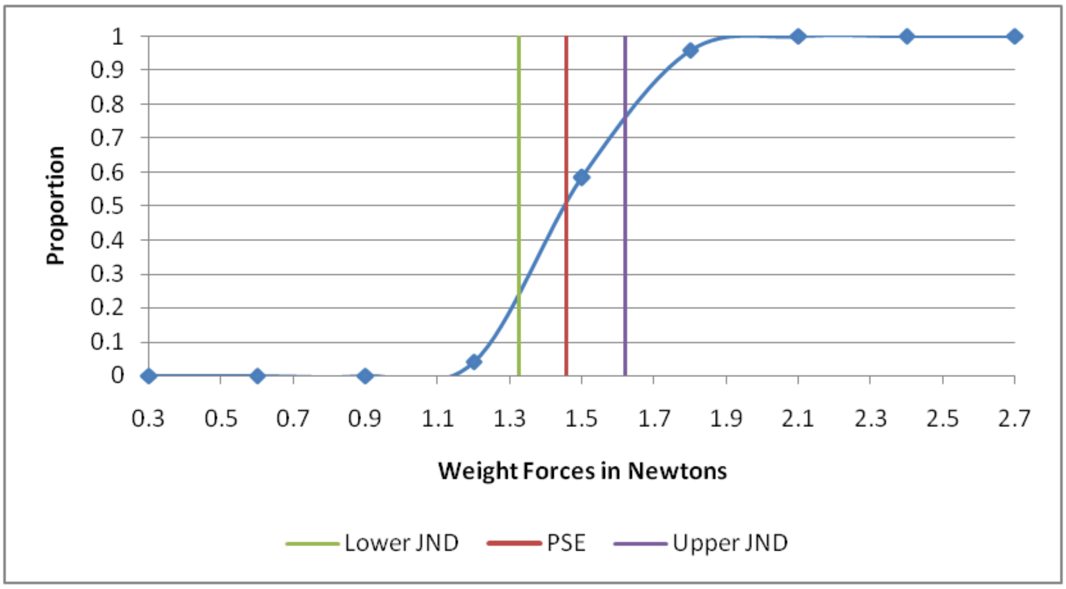

Figure 3.7: JND results for weight discrimination based on the 1.5 Newton force standard stimulus (summarised in Table 3.2).

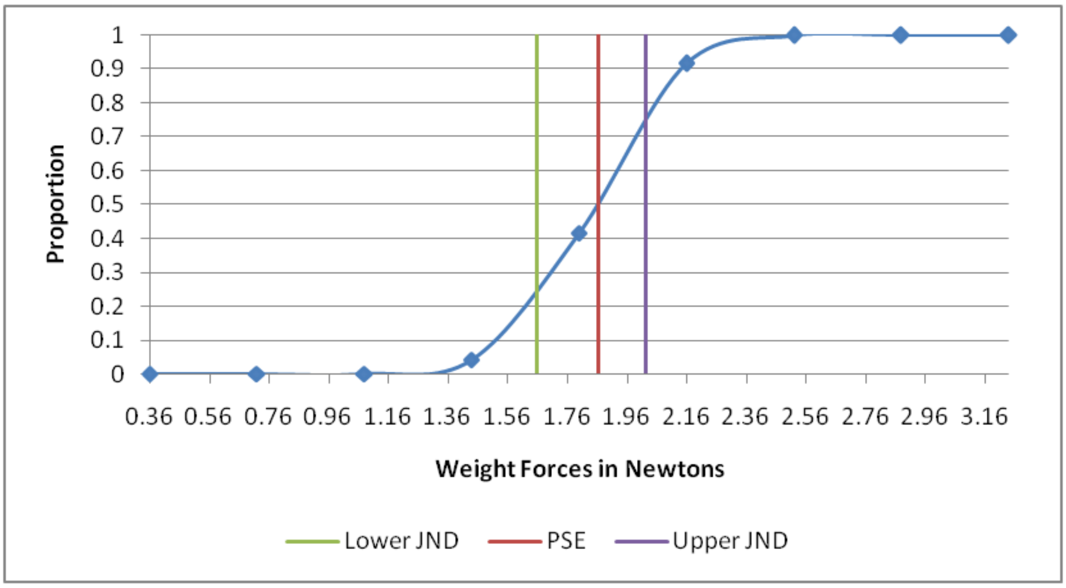

Figure 3.8: JND results for weight discrimination based on the 1.8 Newton force standard stimulus (summarised in Table 3.2).

ST	PSE	SEM	JND^L	JND^U	Average JND	Weber Fraction
1.2N	1.179	±0.035	0.109	0.136	0.123	10.21%
1.5N	1.456	±0.040	0.130	0.162	0.146	9.73%
1.8N	1.865	±0.052	0.205	0.158	0.182	10.08%
	Average Weber Fraction =					10.01%

Table 3.2: Results of haptic weight perception experiment in the form of JNDs and Weber Fractions for 1.2 N, 1.5 N, and 1.8 N standard stimuli (ST).

The results show minor negative bias PSEs for 1.2 N (i.e., 1.179) and 1.5 N (i.e., 1.456), and a minor positive bias PSE for 1.8 N (i.e., 1.865). There is little difference in the Weber Fractions JNDs, ranging from 9.73 percent to 10.21 percent. The average weight Weber Fraction JND for the three standard stimuli was 10.01 percent. Minor biased PSE of this magnitude is common in psychophysical experiments (Gescheider 1997, pp. 50 - 54) and has also been observed in other research (Allin et al. 2002; Provancher and Sylvester 2009).

The results of the experiments indicate that JND threshold of haptic weight force discrimination is on average 10.01 percent. This is consistent with the 10 percent JND threshold observed for physical weights by Ernst Weber (Kramer (2010). This is also consistent with the 10 percent JND threshold derived in other haptic force discrimination studies (Allin et al. 2002; Dominjon et al. 2005; Hinterseer et al. 2007). However, the JND threshold estimation in this experiment is somewhat dissimilar to those observed by Brewer et al. (2005) and Srinivasan and Basdogan (1997). This could be attributed to the difference in the experimental setup, the tested joints, and the training provided.

One difference between our experiments and the previous studies was that our experiments allowed for free movement of the virtual cube pairs and free arm movement in the subjects. Unlike the constrained haptic objects found in other studies, subjects in our study were given the choice to hold and move an object freely, i.e., up/down and left/right. This freedom maps more naturally to the interaction an online shopper would have when comparing products. However, such freedom in exploration appears not to have a significant effect on the perception of the weight force.

3.8 Chapter Summary

This chapter has documented a psychophysical evaluation to investigate the JND threshold of haptic weight force. The evaluation was conducted to aid in understanding the limitation of the haptic device in terms of the availability of different stimuli to represent physical products when shopping online. Appropriate identification of the available haptic stimuli can enable designers to create consistent sensorial information that can lead to improved usability (Callahan and Koenemann 2000).

The experiment was conducted using a Phantom Omni haptic device involving 24 subjects. The experiment consisted of 27 trials in which subjects were encouraged to lift a pair of virtual cubes and move them freely to make a judgment of their perceived heaviness. Information collected across three standard weight stimuli was used to compute accuracy transitions for perceived weight. Regardless of free exploration, results showed that a reliable JND threshold for weight perception, with a Phantom Omni, was 10.01 percent. Further discussion is offered in Chapter 6.

Chapter 4: Psychophysical Evaluation of Haptic Frictional Surface Discrimination

4.1 Introduction

The previous chapter, i.e., Chapter 3, reported on one of two initial psychophysical experiments to measure the JND thresholds of haptic weight force. This chapter describes another psychophysical experiment of close haptic frictional surface stimuli. Like the haptic weight force experiment, free exploration was practiced to mimic the online shopping context using psychophysical methods of measurement (refer to Aim 1 in section 1.4). Along with weight, the identification of the haptic friction force JND threshold is important to the primary haptic shopping investigation (see Chapter 5), where various representations of product surface textures are required

4.2 Motivation

Much prior research has focused on JNDs for friction in human subjects, but none, to the author knowledge, has tailored findings to the online shopping domain. Provancher and Sylvester (2009) report JND thresholds of 0.28–18 percent when examining virtual friction stimuli through finger exploration using a Phantom Premium 1.0 device, corresponding to standard static coefficients for friction stimuli of 0.2–0.8. Biet et al. (2008) report a JND threshold as low as 9 percent using a friction-based tactile display that stimulated friction by generating an air gap between the finger and a high-frequency vibrating plate. In an experiment involving the use of bare index fingers to feel friction on a glass surface, Samur et al. (2009) report an 18 percent JND threshold. Hinterseer et al. (2007) describe a haptic prediction model based on human perception that fell between the JND thresholds of 5 and 15 percent.

However, these findings, while suggestive, cannot be incorporated into online shopping applications due to the constraints on the experimental setups and the suitability of the technology. Motion constraints on the arm or fingers found in other friction experiments do not realistically reflect shopping activity, where surface exploration is experienced freely. Furthermore, high-end haptic technologies, such as those used by Provancher and Sylvester (2009), may not be appropriate for online shopping due to the amount of space required to house such devices. Others, such as those implemented by Biet et al. (2008), offer tactile feedback (e.g., to simulate textures), but do not provide kinaesthetic feedback (e.g., to simulate weights). For haptic-based online shopping, the use of general devices with various feedback cues is required.

Given these variations in JND thresholds using different experimental techniques and technologies, there is a need for further investigation to support haptic-based shopping applications. This study explores JND threshold for a Phantom Omni haptic device using free virtual surface exploration through a probe. As discussed in section 2.2.2.2, probe examination can be effective in discriminating between different types of surfaces.

4.3 Aims

The work described here aims to examine the differential thresholds for frictional surfaces, an important haptic feature for product comparison. More precisely, the experiment attempts to identify the minimum JND threshold needed to distinguish between two haptically simulated frictional surfaces across a range of frictional surfaces in an online shopping context.

4.4 Objectives

The objective of this study is to develop an experimental platform to allow users to interact with and compare simulated virtual frictional surfaces. The platform allows for the judgment assessment of different combinations of virtual frictional surfaces, as well as the recording of the judgmental decision responses given, in order to achieve the stated aims of the study.

4.5 Experimental Design

The experiment utilised the same environmental setup as was used in the evaluation of haptic weight discrimination discussed in Chapter 3. However, to create various frictional forces, two configurable fields were utilised; one field for static coefficient of friction (StaticCF) and another for dynamic coefficient of friction (DynamicCF), with values ranging from 0 to 1. These fields were used to create the stick-slip motion behaviour discussed in section 2.2.2.2. Pink noise (from www.simplynoise.com) was played throughout the experiment using a set of headphones in order to mask any auditory cues from the environment or the haptic device. In addition, the haptic device was placed on a double layer of mouse pads to reduce vibration noise transmitted from the surface of the experiment desk.

4.5.1 Experimental Environment

In order to identify the differential thresholds for haptic frictional surfaces, a dedicated experimental environment was developed to conduct a psychophysical investigation of haptic frictional force discrimination. The environment resembles the one used in the previous experiment a great deal (see section 3.5.1) in that it allows discrimination trials, expressed in Newton force, to be carried out according to the psychophysical measurement method of constant stimuli and the method of transitions. However, in this case, it shows an identical pair of experimental surfaces. These surfaces provide frictional forces to the human hand when touched using the Phantom Omni force feedback pointer to examine their stickiness (see Figure 4.1).

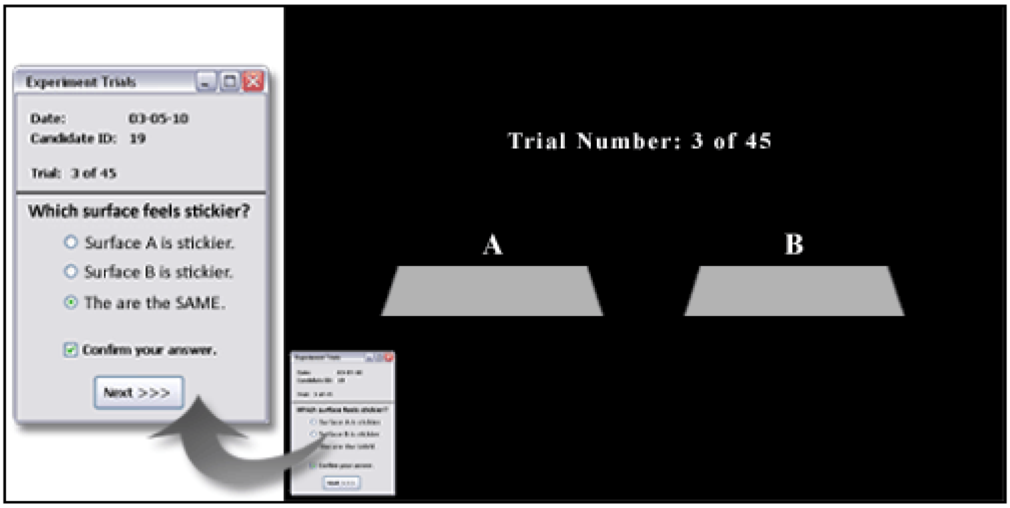

Figure 4.1: Visual output for the haptic frictional surfaces discrimination experiment.

In order to construct frictional forces on each surface, the *FrictionalSurface,* a custom node provided by the H3D API, was manipulated to allow for the simulation of various stickiness sensations. The node has adjustable *dynamicFriction* and *staticFriction* fields that allow dynamic coefficient of friction (DynamicCF) and static coefficient of friction (StaticCF) frictional forces to be rendered to simulate various stickiness sensations on the particular surface being examined.

4.5.2 Haptic Friction Forces

Using the *dynamicFriction* and *staticFriction* fields discussed in the previous section, haptic surface frictions were evaluated based on a number of arbitrary StaticCF levels (i.e., 0.1, 0.3, 0.5, 0.7, and 0.9). On each StaticCF level, a DynamicCF standard stimulus of 0.5 was evaluated against nine DynamicCF comparison stimuli of equal distances (i.e., 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9), as shown in Table 4.1. The extreme high and low of StaticCF and DynamicCF were selected to fall between 0 and 1, which are the lowest and highest frictional force magnitudes the haptic device can simulate. Such spread coverage within the haptic feedback device capability is necessary so that the comparison stimuli of the superior and inferior magnitudes are discriminated without difficulty when compared to the DynamicCF standard stimuli.

On each StaticCF level, the DynamicCF standard stimulus was paired with the comparison stimuli, which resulted in 45 experimental friction force trials, i.e., 9 x 5. Experimental trials were sequenced in a random order using a random number generator,[26] with the standard stimulus used first for half of the trials and the comparison stimuli used first for the other half, to provide unbiased JND estimates, as demonstrated by Gescheider (1997, pp. 50 - 54).

[26] www.stattrek.com/Tables/Random.aspx [Accessed 20 January 2011].

StaticCF Levels	DynamicCF Standard Stimulus	Comparison Stimulus Values								
		← ←← Spread → → →								
		-80%	-60%	-40%	-20%	0%	20%	40%	60%	80%
0.1	**0.5**	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.7
0.3	**0.5**	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.5	**0.5**	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.7	**0.5**	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.9	**0.5**	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Table 4.1: Friction forces value used in the haptic surface frictional discrimination experiment trials. Each DynamicCF standard stimulus was compared to nine comparison stimuli at five levels of StaticCF.

4.6 Experimental Method

A within-subjects design was employed in this experiment; that is, all subjects used the same version of the experimental environment. Subjects were randomly exposed to 45 randomly sequenced weight force trials; they were assigned one discrimination task to complete for each trial they were exposed to. All subjects were given a training session to familiarise them with the haptic environment. The training environment' interface and discrimination task were identical to those in the actual experimental environment. However, unlike the experimental environment, the training session consisted of trials of six pairs of haptic friction forces with extremely large stickiness differences, which were repeated if necessary, to allow subjects to become familiar with the interface and the device.

4.6.1 Task

In order to evaluate the haptic friction forces, subjects were are asked to feel a pair of friction forces and rate their perceptions using three rating categories (Burro et al. 2011). As demonstrated in Figure 4.1, subjects were offered three possible answers to the question "Which surface feels stickier?"

- Surface A is stickier.

- Surface B is stickier.
- They are the SAME.

Stickiness was defined as “how hard it is to push the stylus sideways across the virtual surface.” After they had confirmed their answers with a confirmation checkbox, they proceeded to the next trial, until all 45 trials had been completed.

4.6.2 Subjects

All subjects were recruited via opportunistic sampling. Subjects were invited through emails and by placing posters around the university campus. Twenty healthy male subjects, aged 18 to 39, successfully participated in this experiment. They were students from various Durham University faculties and degree programs. All except one was right handed and they used their dominant hand with the haptic device. All were daily computer users.

4.6.3 Procedure

The procedure largely followed that adopted in the haptic weight discrimination experiment discussed in the previous chapter. Upon arrival at the laboratory, subjects were welcomed and asked to take a seat in front of the computer, where they were verbally introduced to the purpose of the study. Upon agreement from the subjects, they were asked to sign a consent form. After a brief demonstration during which the handling instructions for the device and the training environment were given (discussed in section 4.6), a short training session was then carried out. This was to make sure that the subjects had basic understanding of how to operate the environment and perform the discrimination task before they were exposed to the experimental activities.

Following the training session, the experimental session activities began. During the experimental session (see Figure 4.2), subjects could feel the virtual surfaces as often as they liked, and they could also switch between them as often as they liked to compare their stickiness. Once a judgment was made, subjects could then select an appropriate answer that reflected their stickiness judgment for each trial using the mouse. Once an answer was chosen, subjects had to confirm it and press the “Next” button to proceed to the next trial, which they continued to do until the end of the 45 trials. The complete session, including the training phase, lasted for 35-40 minutes. Ethics approval was granted by the School of Engineering and Computing Sciences Ethics Committee at Durham University.

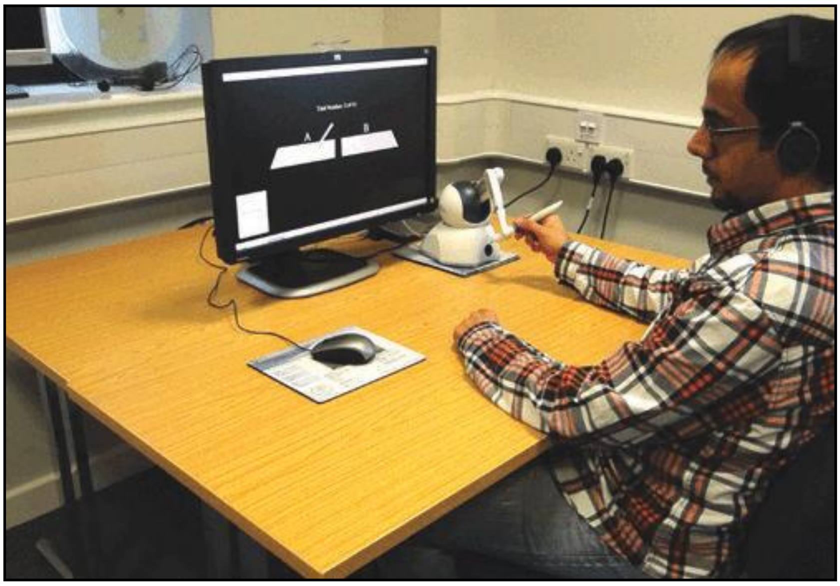

Figure 4.2: Experimental setup for haptic frictional surfaces.

4.7 Results

All 20 subjects successfully completed the experiment. The results for DynamicCF stimuli comparisons were computed separately, based on the level of StaticCF level, to establish the JND via the method of transition, outlined by Burro et al. (2011) (see Appendix B for subjects' responses). The resulting graphs represent the psychometric function with the proportion of stickier responses (*y*-axis), starting from lowest to highest, plotted against values of the comparison stimuli (*x*-axis) are shown in Figure 4.3 - 4.7. The graphs display the proportion of times the standard DynamicCF stimulus, when paired with nine comparison DynamicCF stimuli, was reported as having a greater stickiness at different levels of StaticCF (the nine comparisons were reversed to show the increase). The comparative judgment yielded a sigmoid curve, as a function of the difference in contrast between two stimuli. The JNDs and the corresponding Weber Fractions are summarised in Table 4.2.

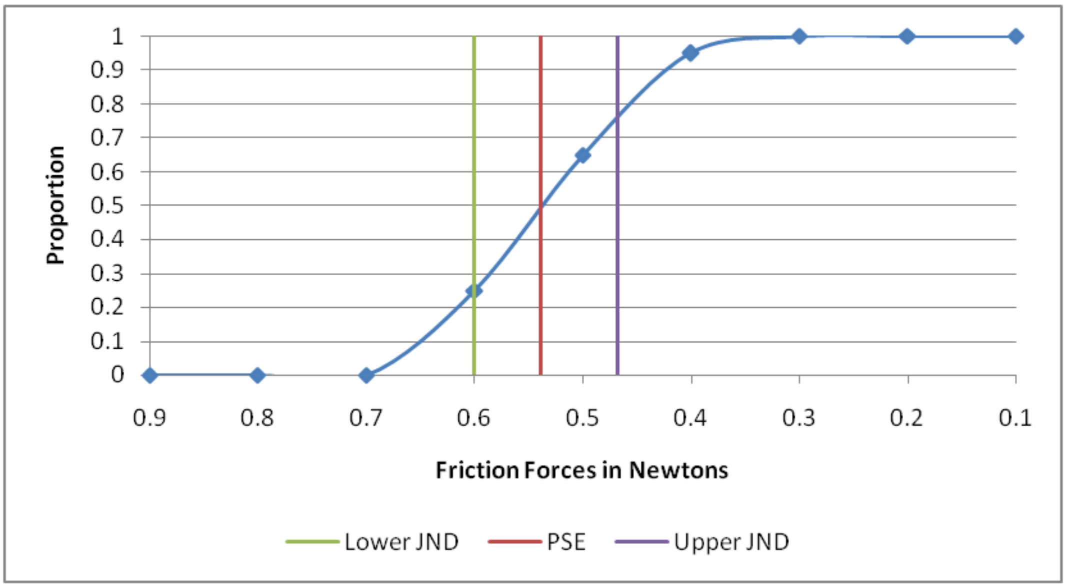

Figure 4.3: Average JND results for stickiness discrimination based on the 0.5 DynamicCF standard stimulus at 0.1 StaticCF level (summarised in Table 4.2).

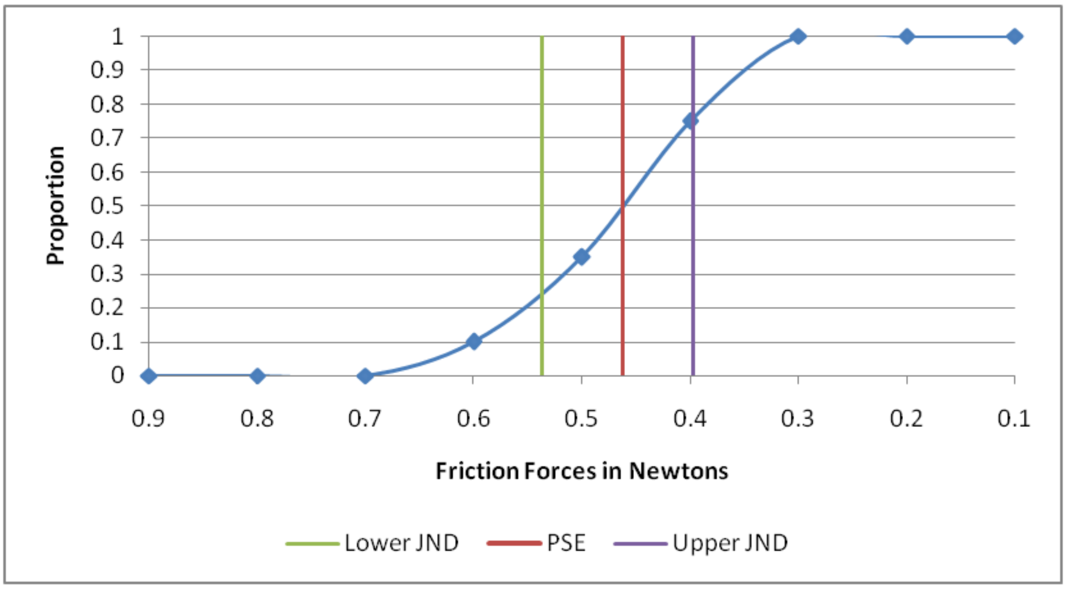

Figure 4.4: Average JND results for stickiness discrimination based on the 0.5 DynamicCF standard stimulus at 0.3 StaticCF level (summarised in Table 4.2).

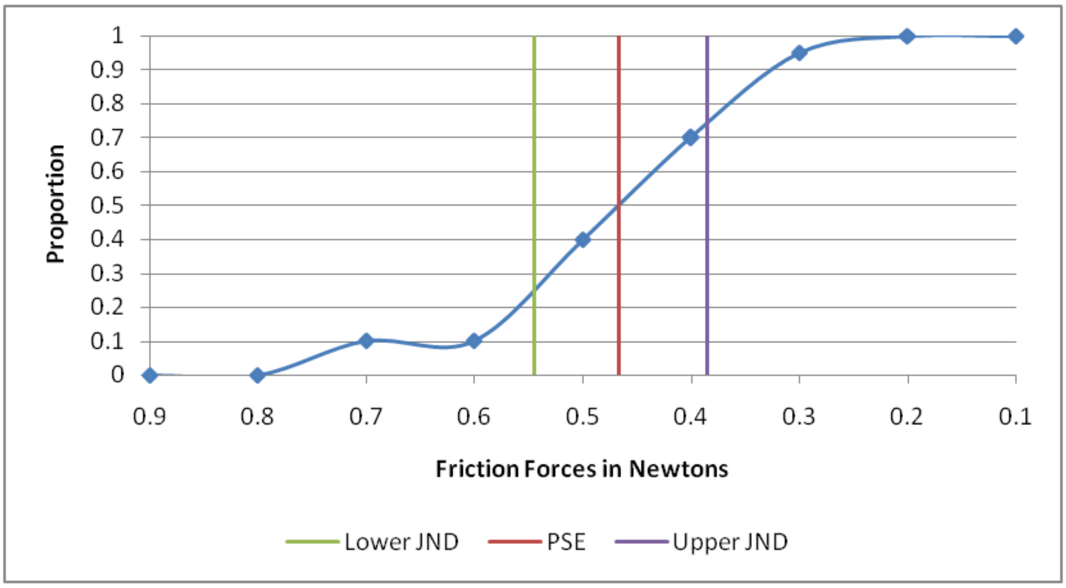

Figure 4.5: Average JND results for stickiness discrimination based on the 0.5 DynamicCF standard stimulus at 0.5 StaticCF level (summarised in Table 4.2).

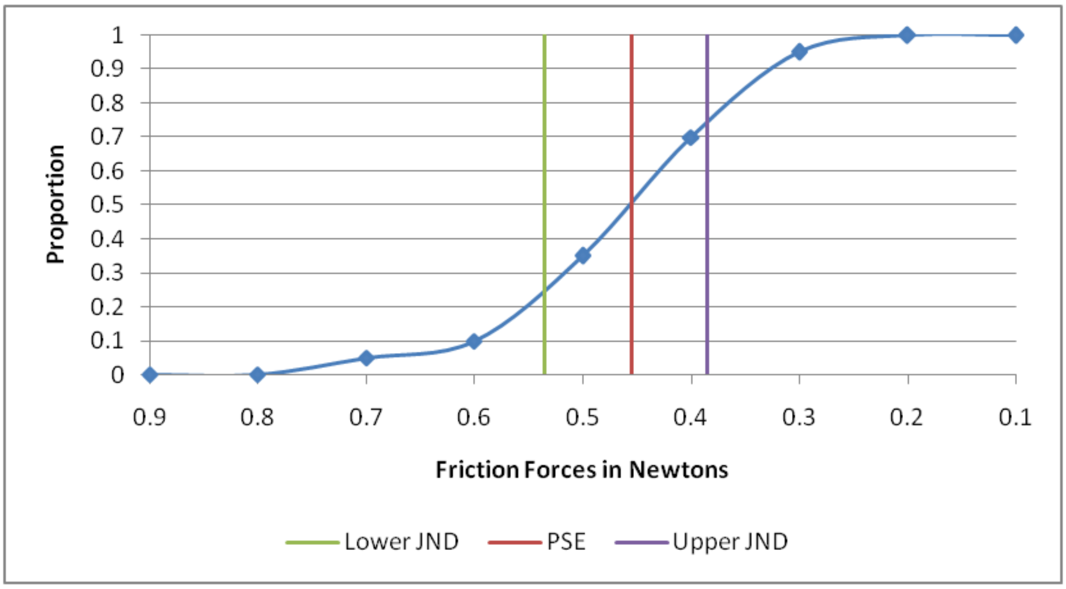

Figure 4.6: Average JND results for stickiness discrimination based on the 0.5 DynamicCF standard stimulus at 0.7 StaticCF level (summarised in Table 4.2).

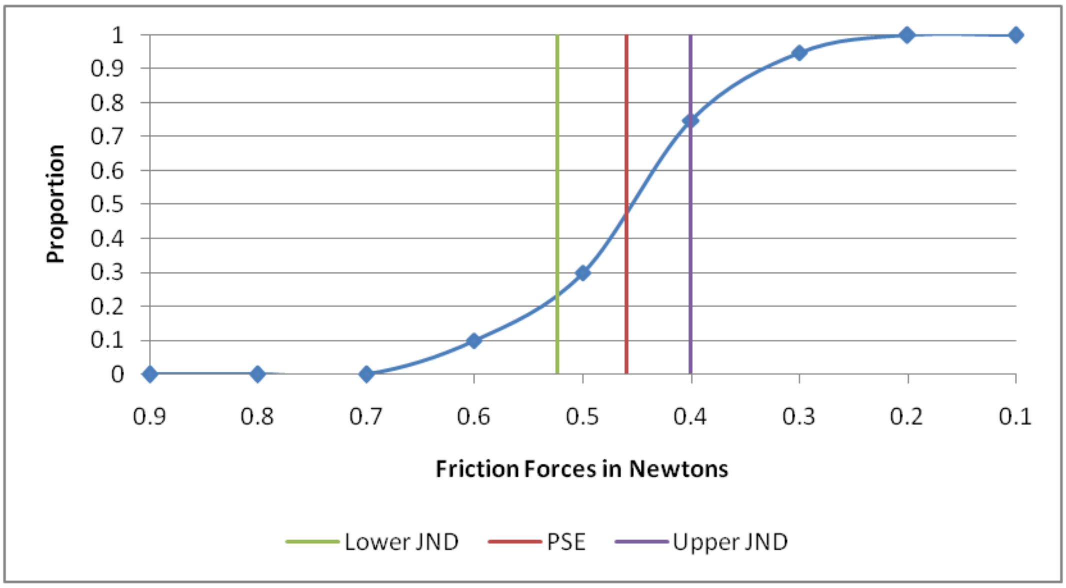

Figure 4.7: Average JND results for stickiness discrimination based on the 0.5 DynamicCF standard stimulus at 0.1 StaticCF level (summarised in Table 4.2).

StaticCF Levels	DynamicCF Standard Stimulus	PSE	SEM	JND^L	JND^U	Average JND	Weber Fraction
0.1	**0.5**	0.538	±0.020	0.062	0.071	0.067	13.3%
0.3	**0.5**	0.462	±0.020	0.075	0.065	0.070	14.0%
0.5	**0.5**	0.466	±0.029	0.078	0.081	0.080	15.9%
0.7	**0.5**	0.455	±0.026	0.080	0.070	0.075	15.0%
0.9	**0.5**	0.459	±0.022	0.064	0.059	0.062	12.3%
						Average Weber Fraction =	14.1%

Table 4.2: Results of haptic frictional surface perception experiment in the form of JNDs and Weber Fractions for the 0.5 standard DynamicCF across all StaticCF levels.

The results reveal a positive bias PSE of 0.538 from the psychometric function under level 0.1 of StaticCF, while other levels of StaticCF show very close negative PSE biases, ranging between 0.466 and 0.455. A biased PSE was found at all considered levels. Subjects tended to underestimate the standard DynamicCF stimuli intensity under level 0.1 of StaticCF. However, the DynamicCF stimuli magnitude is overestimated under all other StaticCF levels. A biased PSE of this magnitude is considered common in psychophysical experiments (Gescheider 1997) and has also been observed in other psychophysical studies (Allin et al. 2002; Provancher and Sylvester 2009), as well as in the haptic weight force experiment discussed in Chapter 3.

The results also indicate approximately constant average JND thresholds using DynamicCF at different levels of StaticCF. DynamicCF perception scored the highest average JND thresholds, at 0.080 on StaticCF level 0.5, while the lowest average JND thresholds were scored on the extreme ends of the StaticCF levels (i.e., 0.1 and 0.9). The average DynamicCF Weber Fractions for the five StaticCF levels is 14.1 percent. The study's outcomes are consistent with those of Hinterseer et al. (2007), who found the haptic prediction model, based on human perception, to be in the 5 to 15 percent range. It is also in a similar range to those of Biet et al. (2008) and

Samur et al. (2009), who observed the JND thresholds of 9 and 18 percent, respectively. However, it is only close to those of Provancher and Sylvester (2009) when the coefficients for friction stimuli are above 0.6 N. This is an important validation of difference thresholds in a free-movement environment.

4.8 Chapter Summary

This chapter has documented a psychophysical evaluation to investigate the JND threshold of haptic frictional surface force. The evaluation was conducted to aid in understanding the limitations of the haptic device in terms of the availability of different stimuli to represent physical products when shopping online. Twenty subjects were recruited for a psychophysical experiment using a Phantom Omni haptic device. The experiment consisted of 45 trials in which subjects were encouraged to feel a pair of frictions and compare them freely to make a judgment of their perceived stickiness, which was meant to mimick a shopping scenario.

DynamicCF information collected across five arbitrary StaticCF stimuli levels was used to compute accuracy transitions for perceived frictional texture. Regardless of free exploration, results showed that a reliable JND threshold for frictional surface perception with a Phantom Omni was 14.1 percent. It should be noted that the small variations of DynamicCF Weber fractions on different levels of StaticCF are to be expected; many human perception abilities follow this type of behaviour at different intensities (Gescheider 1997). Further discussion is offered in Chapter 6.

Chapter 5: Measuring User Experience of Haptic Product Information: A Comparative Study

5.1 Introduction

The previous two chapters (Chapters 3 and 4) described psychophysical experiments needed to construct a better understanding of the haptic stimuli in terms of the availability of different stimuli to represent physical products. The first experiment was conducted to investigate the JND threshold for haptically simulated weight forces, while the second experiment was conducted to investigate the JND threshold for haptically simulated friction forces. Data from these experiments provided support for using JND threshold of at least 10 percent and 14.1 percent for weight and friction thresholds, respectively. These results serve as the basis for the design of an experiment at the next stage, to further investigate the effect of incorporating haptic feedback into B2C interfaces.

While current technological limitations may obstruct the introduction of novel haptic feedback technologies into B2C e-commerce, uncertainties regarding the possible effects of such features in enhancing the online shopping user experience may hinder any future progress in innovation adoption. Little consideration has been given to haptic feedback as an essential part of online shopping experience; most research has focused on the more obvious visual design aspects of online shopping environments. Nonetheless, providing such an enhanced experience can promote greater financial returns to businesses through innovations that allow consumers not only to examine product choices visually, but also to experience their physical properties (Childers et al. 2001).

5.2 Aims

This study aims to introduce the sense of touch through haptic feedback technologies into a realistic online shopping environment and empirically evaluate its usability in enhancing the shopping experience. The study will represent product information haptically to convey two attributes, namely weight and texture. The intention is to study the effectiveness, efficiency and users' satisfaction levels of haptically represented product information in enhancing the shopping experience.

5.3 Objectives

The objective of this study is to develop two experimental online shopping environments; one environment that delivers weight and texture products information using traditional textual approach (Non-HPI) and another that delivers haptic weight and texture products information (HPI). These environments allows shoppers to navigate various products, as well as the recording of times and actions, in order to achieve the stated aims of the study.

5.4 Environment Design

Two realistic online shopping environments were developed. The environments utilised the Phantom Omni force feedback device previously described in sections 3.5 and 4.5. Scenes and haptic forces were rendered on a typical computer running Windows XP operating system. The computer specifications were: Processor**:** Intel Core 2 Duo 2.13 GHz, Memory size**:** 2 GB, 667 MHz DDR2, Graphic Card: ATI Radeon X1650 Series 256MB PCI-Express x16, Visual output: 24inch widescreen LCD monitor.

The choice of colours in the experimental environments (e.g., buttons and text area) was based upon guidelines reviewed by Pearson and Schaik (2003), which aim to improve users' visual perceptions in Web user interfaces. The following subsections will describe the design of the two developed environments in further detail.

5.4.1 Experimental Environments

The main goal of this study is to introduce the sense of touch into online shopping and empirically evaluate its effectiveness in enhancing the shopping experience. Such an addition may offer a heightened sense of realism in online shopping and help customers make more informed choices. In light of this, the proposed environments need to offer shoppers the ability to feel and compare the weights and the surface textures of various products through an easy-to-use interface. However, due to the lack of usability evaluation methods for haptic environments (Smith and Todd 2007; Khan et al. 2011a), this research followed common Web interface designs and applied a usability heuristics evaluation checklist, such as those documented by Nielsen (1993, pp. 115 - 155).

Two existing e-commerce websites that sell electronic goods were examined in order to review the interface design and the main functionalities currently provided to assess products. The goal was to then enhance the current process to include the ability to feel products. In section 5.4.1.2, the proposed interface, which was derived from current e-commerce designs and evaluated against Nielson's heuristics (see

Appendix C), is introduced. This evaluation was meant to reduce unwanted user interaction challenges caused by obvious threats to the usability of the environments, such as those highlighted in section 2.4.2.

5.4.1.1 Exploring Common Websites

This section will briefly review design characteristics for comparing products on two well-known online business enterprises, Comet[27]and Currys.[28] Both websites provide common facilities for locating the desired products, such as a navigation bar where products are categorised by type, and a search facility to find a product in the online catalogue. Once a search is placed through the navigation bar or the search facility, the system lists the matching products (see Figure 5.1 and Figure 5.2). The list includes the product's name, a brief description, an image, and the opportunity to learn more or to compare products side-by-side.

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[27] Website address: www.comet.co.uk [Accessed 25 September 2011].

[28] Website address: www.currys.co.uk [Accessed 25 September 2011].

Figure 5.1: Comet website design characteristics [A = Product images, B = Products name/more info, C = Comparison indicator, D = Description, F = Comparison tool].

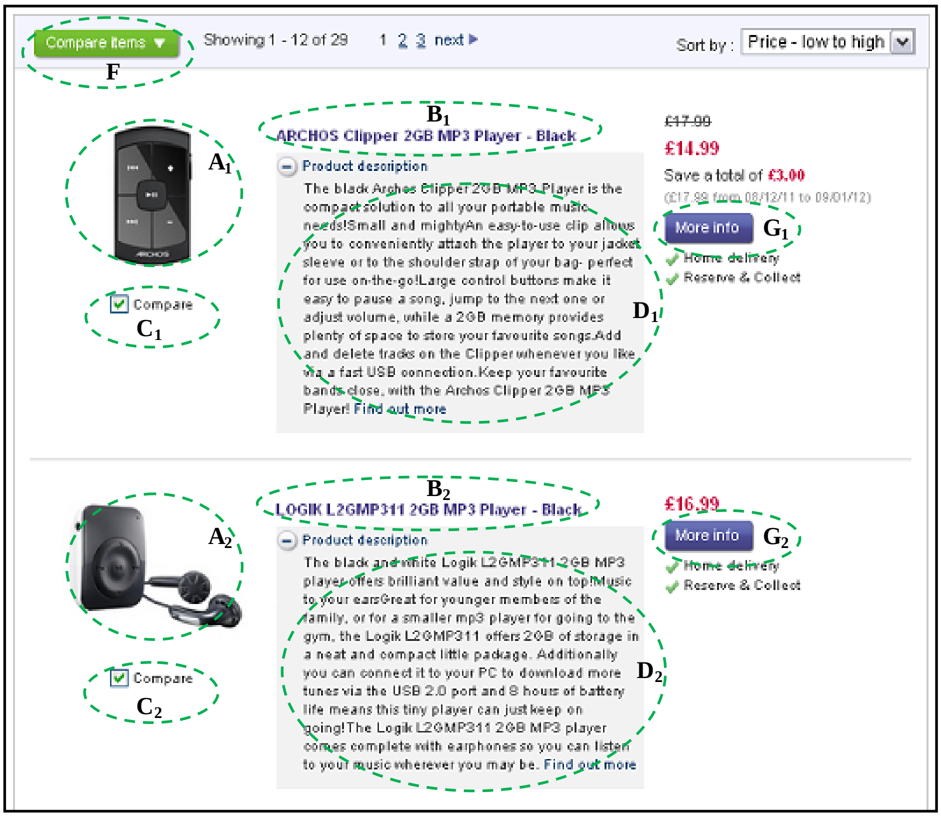


Figure 5.2: Currys website design characteristics [A = Product images, B = Products name/ more info, C = Comparison indicator, D = Description, F = Comparison tool, G = More info].

At this stage, shoppers have the choice to learn more about a particular product or to compare products. To learn more about a particular product, shoppers simply click on the product's name or on the "More Info" button. If shoppers wish to make a side-by-side comparison, then they have to click the "Compare" button after ticking two or more products for comparison (see Figure 5.3 and Figure 5.4). The list includes the product's name, image, price, and features, as well as the ability to choose products to purchase for later checkout.

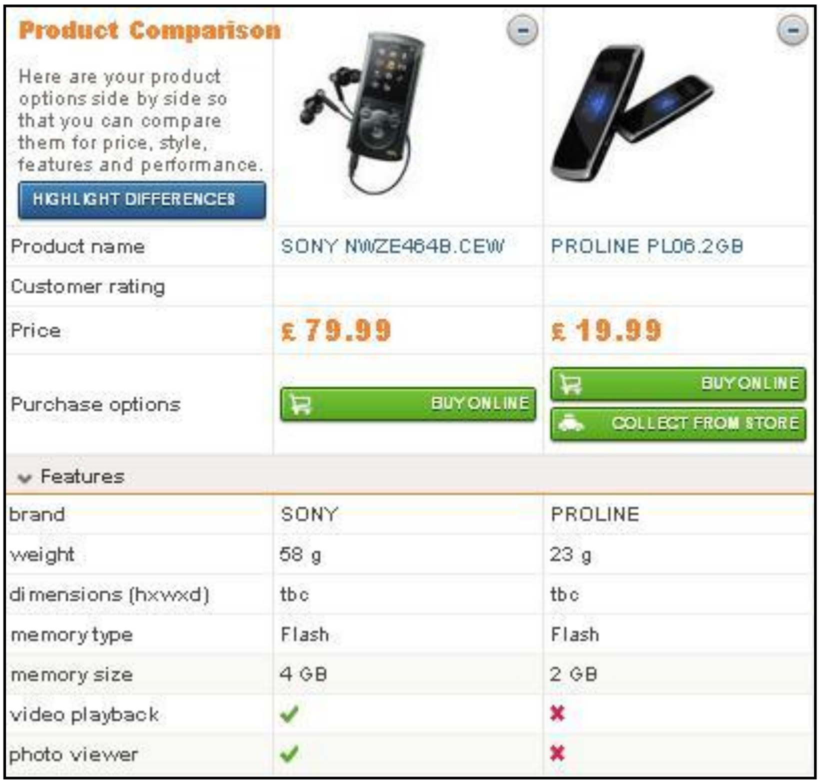


Figure 5.3: Comet Side by side products' comparison.

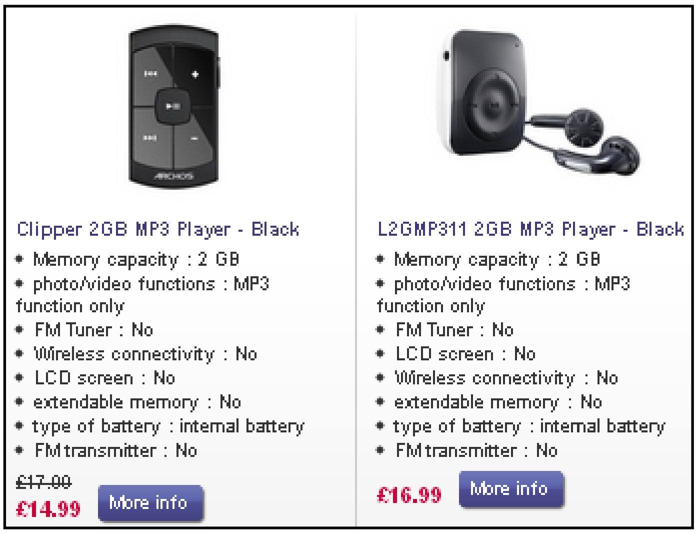


Figure 5.4: Currys Side by side products' comparison.

As seen on the characteristics above, despite their differences with respect to visual appearance, both Comet's and Currys's websites share typical B2C e-commerce website characteristics, including:

- Product image.
- Product name/model.
- Product description.
- Product features (e.g., weight and dimensions).
- Product price.
- The ability to view a single product's information.
- The ability to compare different products.
- Shopping basket.

5.4.1.2 Experimental Environments Design

The previous section (section 5.4.1.1) briefly explored common methods for the interface and navigation of website design in typical B2C e-commerce settings. Matching products along with brief description are normally given to shoppers at the beginning in order for them to formulate an initial idea about the products. At this stage, shoppers have a navigational choice: they can either acquire more product information or compare products side-by-side before adding the desired product to the basket.

To reflect this design exploration, the experimental shopping environments were developed to resemble such e-commerce settings and incorporate haptic feedback functionalities to achieve a desirable interactional experience for haptic online shopping. Nielson's (1993) heuristics evaluation checklist was also applied whenever possible to ensure that the user interface was kept as simple and user-friendly as possible. Two experimental shopping environments were developed in this study. Both displayed the same products and followed the same design and interface structure, but with different product information interaction (i.e., HPI and Non-HPI). The interface structure consisted of three screens, as illustrated in Figure 5.5.

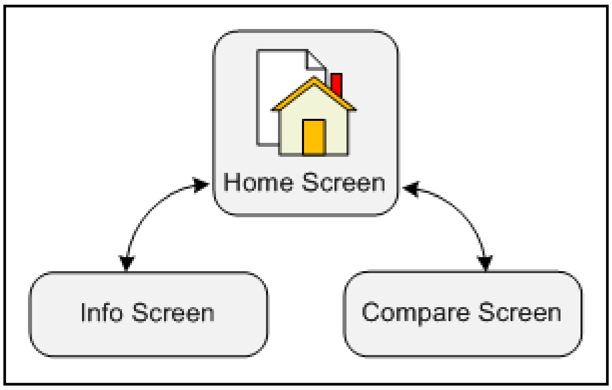


Figure 5.5: Haptic Environments Interface Structure

All screens are clearly labelled at the bottom left of the environments' interfaces. Screens and buttons were labelled using familiar words in online shopping (e.g., "More Info" screen, "Add to Basket" button). Figure 5.6 shows the "Home Screen" interface design, which is identical in both environments (see Appendix D for examples). Subjects have the ability to explore six items, but could only compare two at a time due to concerns about the visual space available at the "Compare Screen" in the HPI the environment (see Figure 5.8). This limitation was overcome by displaying text beside the "Compare" button in the "Home Screen" that instructed subjects to select two products for comparison using the "Add to Compare" selection buttons. Validation checks were also used to account for this limitation by displaying appropriate error messages whenever fewer or more than two items were selected for comparison. Only if the validation checks were successful would clicking the "Compare" button take the user to the "Compare Screen" interface. Both shopping environments utilised the haptic device to navigate between screens with the various buttons provided.

Figure 5.6: The "Home Screen" Interface design for the experimental environments. Identical screens were used in both the Non-HPI and HPI the environments.

The experimental environments adopted similar buttons behaviours to those found in many common websites that utilise mouse-based interactions, such as changing colours when the cursor hovers over a button to indicate pre-selection or when a selection is made. However, since the haptic environment employs 2.5 dimensional (2.5D) visualisation capabilities, hovering may not be used as an indicator of pre-selection. Instead, when touched, buttons will glow, indicating contact between the cursor and the selected button, which indicates pre-selection action. The environments have two types of buttons: action buttons, displayed without a coloured border, and selection buttons, displayed with a coloured border. As their names imply, action buttons are used to submit operations, while selection buttons are used to activate and deactivate any combination of buttons. To submit an operation, subjects will first have to touch the action button until it glows on the screen and then press the stylus button. However, to make a selection, users will first have to touch the desired selection button until it glows on the screen, then press the stylus button, which will change the button border colour of the selected button from orange (inactive) to green (active), indicating a selection. These buttons behaviours are important when subjects explore the shopping environments and contribute to usability of the system (see section 2.4.2).

In order to create a shopping environment that encourages subjects to explore and learn more about the available products, the environment was selling handheld massagers with different features. Besides, along with other features, weight and massaging-surface experience are believed to be among the most important aspects of this type of product (McDonagh et al. 2005), thus allowing for effective and balanced comparisons between products. Moreover, the products' brands were eliminated and they were priced at a close range (i.e., £31.99–£49.99), with an increment of around £4. This was to reduce the impact of brand name and price on consumer choices (Degeratu et al. 2000). All products displayed were grey-scale images to prevent product choice based on colour. Other product attributes, such as weight, the feel on the skin, intensity levels, dimensions, and power options varied equally to promote comparison.

Figure 5.7 shows the "Compare Screen" interface design for the Non-HPI environment, while Figure 5.8 shows the "Compare Screen" interface design for the HPI environment (see Appendix D for the "More Info Screen" screenshots, which are similar to the "Compare Screen," but display one product at a time). The Non-HPI shopping environment displayed all product information as text accompanied by product images. In the HPI shopping environment, but not in the Non-HPI, textual descriptions of the weight and feel on skin were removed (see Figure 5.9) and replaced by haptically simulated information. Product weights were conveyed through middle sliders that imposed downward force when held, and products' feel on skin was conveyed through bottom surfaces that provided haptic sensation when stroked using the haptic pointer. The technique adopted for conveying haptic information was developed in light of the previous psychophysical experiments on haptic weights and textures (see Chapters 3 and 4). Appropriate instruction messages, which were positioned under each haptic weight and texture functionality, were provided.

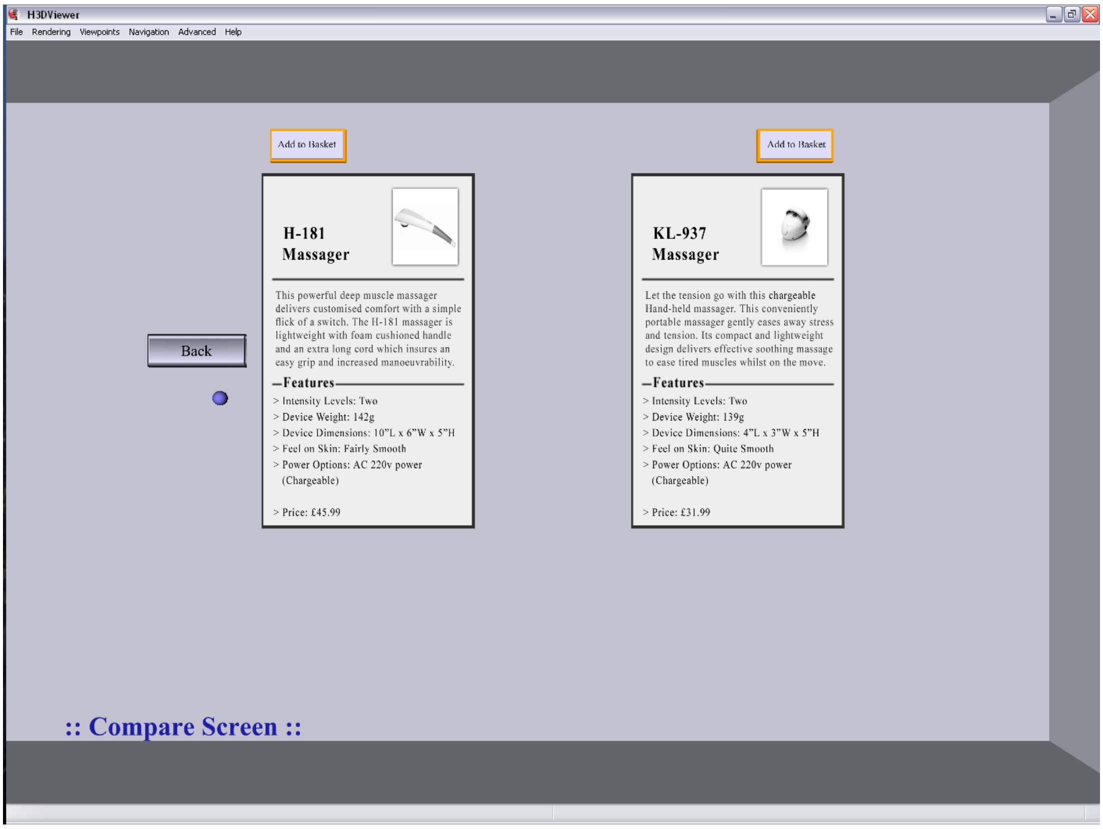


Figure 5.7: Compare screen for the Non-HPI environment. Weight and feel on skin information were presented in the text alongside other textual product information.

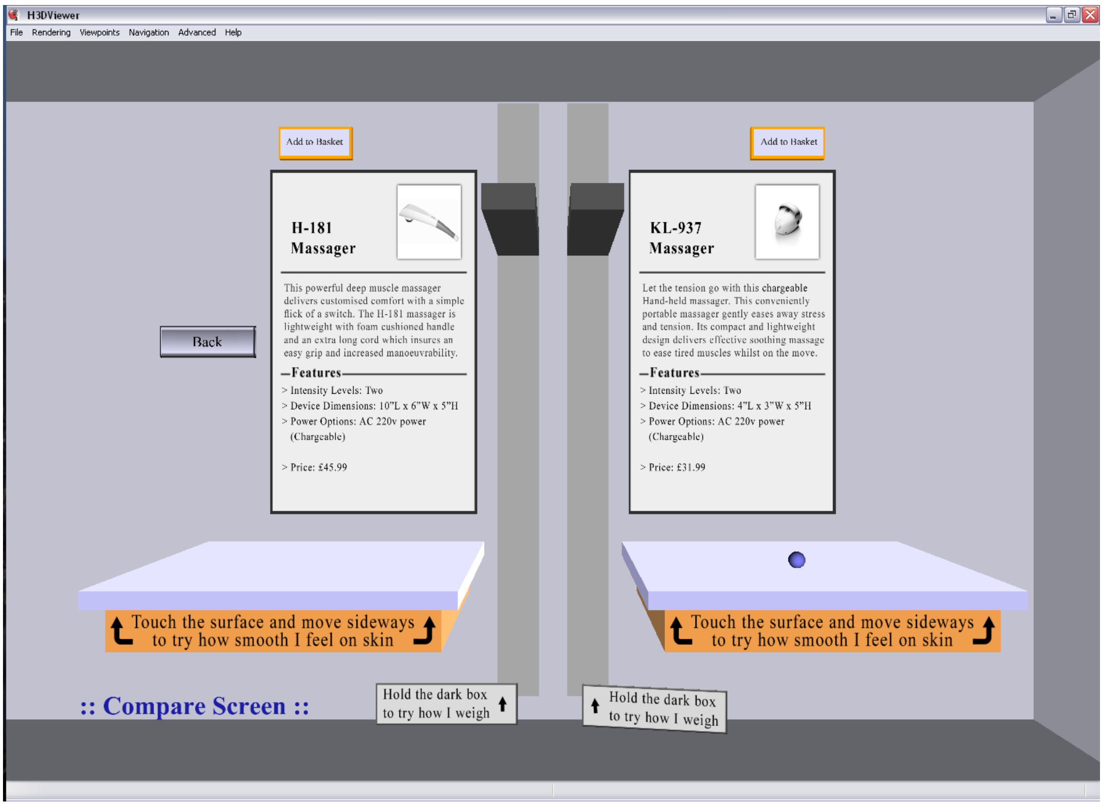


Figure 5.8: Compare screen for the HPI environment. Weight and feel on skin information were haptically simulated using middle sliders in the middle of the screen and texture enhanced surfaces under product descriptions.

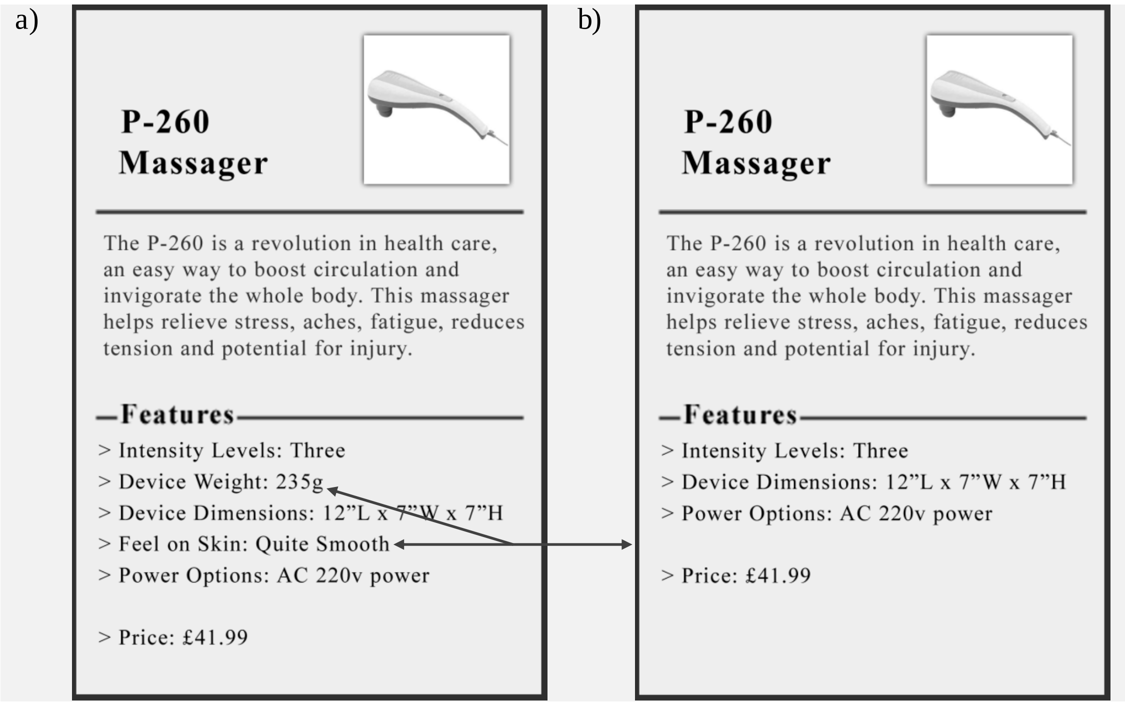


Figure 5.9: Comparison of the textual information provided in the Non-HPI (a) and the HPI (b) interfaces. Device weight and feel on skin are omitted in the HPI interface and replaced by haptic information as illustrated in Figure 5.8 (for a complete list of products information, refer to Table 5.2).

5.4.2 Products Information

As stated in the previous section, the experimental environments had six identical products; in other words, the Non-HPI environment had six products that were also used in the HPI environment. The products were presented in the same exact location in both environments. This section will give more details on how product information was distributed across the six products. Product information consists of two levels of information, which were inspired by the common interface designs described in section 5.4.1.1.

The first level, accessible from the "Home Screen" that was used in both experimental environments, as illustrated in Figure 5.6, served as a starting point for subjects to explore the available product choices. This level provided brief product information, consisting of four types of details regarding the product: model, image, a short description, and price. Product choices were ordered alphabetically from left to right (in the "Home Screen") by their model name, but this did not necessarily impose a particular choice, since model names were not genuine. Table 5.1 demonstrates the first level of product information and the equivalent code that was used throughout the thesis to identify each product.

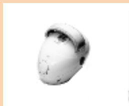
Massager Code	Model Name	Image	Short Description	Price
M1	DN-53H		Portable relaxation.	£39.99
M2	H-181		Deep muscle massager.	£45.99
M3	KL-937		Conveniently portable.	£31.99
M4	P-260		Invigorate the whole body	£41.99
M5	YM-47X		Soothing and relaxing!	£49.99
M6	ZE-383		Unique and comfortable.	£35.99

Table 5.1: First level product information used in both the Non-HPI and the HPI environments.

The second level, accessible from the "More Info Screen" and the "Compare Screen," served as a space for subjects to learn more about the available product choices. This level provided wider product information that consisted of three areas, as shown in Figure 5.9. The top area showed the product model name and image, the middle area showed a long description, and the bottom area showed the product features, which were comprised of intensity levels, device weight, device dimensions, device feel on the skin, power options, and price. Since the top area was a replication of the same information offered at the first level (see Table 5.1), Table 5.2 shows only the middle and bottom areas of the second-level product information, which are common to both environments. However, the device's weight and the feel on the skin (i.e., friction texture) features in the bottom area were manipulated according to the experimental environment (i.e., Non-HPI or HPI).

Massager Code	Long Description	Intensity Levels	Device Weight		Device Demotions	Feel on Skin (Friction Texture)		Power Options	Price
			Non-HPI	HPI		Non-HPI	HPI		
M1	This user-friendly massager is so easy to use that you can simply push its head to switch it on. The pocket-sized DN-53H is also perfectly portable for on-hand relaxation whenever and wherever you need it.	Three	298g	2.97N	6”L x 4”W x 6”H	Fairly Smooth	SF: 0.1N DF: 0.91N	AC 220v power	£39.99
M2	This powerful deep muscle massager delivers customised comfort with a simple flick of a switch. The H-181 massager is lightweight with foam cushioned handle and an extra long cord which insures an easy grip and increased manoeuvrability.	Two	142g	1.32N	10”L x 6”W x 5”H	Fairly Smooth	SF: 0.1N DF: 0.91N	AC 220v power (Chargeable)	£45.99
M3	Let the tension go with this chargeable hand-held massager. This conveniently portable massager gently eases away stress and tension. Its compact and lightweight design delivers effective soothing massage to ease tired muscles.	Two	139g	1.32N	4”L x 3”W x 5”H	Quite Smooth	SF: 0.5N DF: 0.78N	AC 220v power (Chargeable)	£31.99
M4	The P-260 is a revolution in health care, an easy way to boost circulation and invigorate the whole body. This massager helps relieve stress, aches, fatigue, reduces tension and potential for injury.	Three	235g	2.31N	12”L x 7”W x 7”H	Quite Smooth	SF: 0.5N DF: 0.78N	AC 220v power	£41.99
M5	Beautifully designed massager that favours any zone of your body with soothing massage. The single-headed massager with its streamlined handle delivers powerful and relaxing massages.	Three	302g	2.97N	11”L x 6”W x 6”H	Very Smooth	SF: 0.1N DF: 0.52N	AC 220v power	£49.99
M6	The ZE-383 is a unique massage instrument that can be kept with you at all times. Comfortably lies in the hand, causing no fatigue when being used. The massager is ideal for tension, pain, fatigue.	Two	231g	2.31N	4”L x 4”W x 5”H	Very Smooth	SF: 0.1N DF: 0.52N	AC 220v power (Chargeable)	£35.99

Table 5.2: All second-level product information was identical in both experimental environments, but the device weight and the feel on the skin (i.e., friction texture) features were manipulated according to the experimental environment (N = Newton force, SF = static friction, DF = dynamic friction). See Table 5.1 for product images.

In the Non-HPI environment, the device's weight and the feel on the skin were conveyed through textual description, but these were haptically simulated in the HPI environment. Weight and feel on the skin were devised to have different levels of sensations. The weights were distributed around three levels: light (139 g and 142 g), medium (231 g and 235 g) and heavy (298 g and 302 g). Although each level has different intensities, the small gap should not have been physically felt by the human sensory perception, as it was below the 10 percent JND threshold (Kramer 2010). Therefore, since each of the two weights at each level were peceptually the same, they were mapped to one haptic force stimulus, as illustrated in Table 5.2.

Similarly, the intensities of the devices' feel on the skin were distributed around three levels: low smoothness (fairly smooth), medium smoothness (quite smooth), and high smoothness (very smooth), each of which was mapped to a frictional stimulus. The wording (i.e., *fairly*, *quite*, and *very*) was based on linguistic term representations suggested by *Oxford Advanced Learner's Dictionary*[29], which regards the word *quite* as being a little stronger than the word *fairly*. It is important to clarify that neither the mapped weights nor the mapped textures necessarily represent real-world stimuli, but rather were mapped based on the experimenter's perception of relative stimulus magnitudes.

In light of the previous psychophysical experiments (see Chapters 3 and 4), haptic weights and feel on the skin (i.e., friction texture) stimuli values were produced to

[29] Refer to *Oxford Advanced Learner's Dictionary* for the definition of adverb *fairly* at http://oald8.oxfordlearnersdictionaries.com/dictionary/fairly [Accessed 15 February 2012].

represent various products (see Table 5.2) using Weber Fractions. The estimated Newton force Weber Fraction for weights is 10.01 percent, while the estimated dynamic friction Weber Fraction for the five static friction levels is 14.1 percent. Based on those Weber Fractions, separation factors of 0.33 for the Newton force stimuli and 0.13 for the dynamic friction stimuli were calculated. The Newton force factor was calculated based on the 3.3 Newton force (i.e., 3.3 x 0.101 = 0.33), while the dynamic friction factor was based on the 0.91 friction force (i.e., 0.91 x 0.141 = 0.13). Table 5.3 and 5.4 below show ten Newton force stimuli values and seven dynamic friction values on each static friction level. All values were separated based on their respective factorial separations.

Force Stimuli				
3.3	**2.97**	2.64	**2.31**	1.98
1.65	**1.32**	0.99	0.66	0.33

Table 5.3: Newton force stimuli values based on 0.33 separation factor. The ones used in this study to represent weights are highlighted (also see Table 5.2).

Static Friction Stimuli	**Dynamic Friction Stimuli**						
0.9	0.91	0.78	0.65	0.52	0.39	0.26	0.13
0.7	0.91	0.78	0.65	0.52	0.39	0.26	0.13
0.5	0.91	**0.78**	0.65	0.52	0.39	0.26	0.13
0.3	0.91	0.78	0.65	0.52	0.39	0.26	0.13
0.1	**0.91**	0.78	0.65	**0.52**	0.39	0.26	0.13

Table 5.4: Dynamic friction (DynamicCF) stimuli values based on 0.13 separation factor for each static friction (StaticCF) stimulus. The ones used in this study to represent texture are highlighted (also see Table 5.2).

The reason for the use of factorial separation is that it allows intensities to decrease gradually while maintaining a systematic increase of the Weber Fraction. For example, the Weber Fraction between Newton force 3.3 and 2.97 is 10.01 percent, while the Weber Fraction between Newton force 2.31 and 1.98 is actually 14.3 percent. Such an increase is necessary at this stage to introduce diverse sensation stimuli that encourage exploration: some sensation stimuli that are just noticeable and some that are clearly noticeable.

For this research, weight values were chosen to represent a small gap difference between 2.97 N and 2.31 N, a medium gap difference between 2.31 N and 1.32 N, and a large gap difference between 2.97 N and 1.32 N. Likewise, dynamic friction values were chosen to represent textures at different intensities, where two of these fell into the same static friction level, and one into another level, as illustrated in Table 5.4. Weights and frictional textures will provide six comparisons each, where subjects are able to experience the same or different sensation intensities.

5.5 Experimental Hypotheses

As discussed in section 2.5, providing haptic knowledge regarding products could potentially enhance the experience of online shopping. Thus, the study’s aim is to investigate whether such phenomena occur when haptic product information regarding weight and texture are utilised (i.e., HPI environment) and when textual product information regarding weight and texture are utilised (i.e., Non-HPI environment). The data collected in this study were analysed according to the following hypotheses, which address effectiveness, efficiency, and user satisfaction in the enhanced shopping environment:

***Effectiveness*:** It is believed that accomplishing the assigned tasks successfully within a given timeframe, as well as the quality of the task output, are essential indicators of system effectiveness (Faulkner 2000, pp. 117 - 118; Hornbæk 2006). Unlike the Non-HPI environment, the HPI environment involves the use of haptic weight and texture interactions without the presence of textual weight and texture information. Such interaction will provide a more natural channel of evaluation that replicates real-world product evaluation by allowing subjects to personally experience a product through interactive media. Hence, it is reasonable to assume that haptic evaluation is as effective as textual evaluation in terms of accomplishing the assigned tasks successfully, but with a dissimilar output quality. Therefore, the following hypotheses are proposed.

> **Hypothesis 1:** The experimental HPI environment will be similarly effective in comparison with the Non-HPI environment in terms of the rate of accomplishing the assigned tasks successfully within a given timeframe.

> **Hypothesis 2:** The experimental HPI environment will show dissimilar output quality in comparison with the Non-HPI environment in terms of the products selected for the accomplishment of the assigned tasks.

Efficiency: Time spent and the actions required serve as indicators of system efficiency in terms of the effort required to accomplish the tasks (Nielsen 1993, pp. 192 - 195; Faulkner 2000, pp. 118 - 119). However, compared to the Non-HPI environment, the HPI environment adds a further level of interactivity, which is introduced by the ability to haptically feel products' weight and texture features. This may induce an increase in interaction time, but it is believed that the number of actions required (i.e., the number of "Compare" and "More Info" button clicks) to find the desired product will decrease in the HPI environment as a result of the added confirmatory evaluation through haptic weight and texture. For this reason, it is reasonable to assume that the decrease in the number of actions required in HPI environment will result in comparable time spent in the two environments. Therefore, the following hypotheses are proposed.

> **Hypothesis 3:** The experimental HPI environment will be similarly efficient in comparison with the Non-HPI environment in terms of the time spent for the accomplishment of the assigned tasks.

> **Hypothesis 4:** The experimental HPI environment will be more efficient in comparison with the Non-HPI environment in terms of the number of actions required to accomplish the assigned tasks.

Satisfaction: Satisfaction or dissatisfaction provides a direct way for users to express their preferences and opinions upon completion of an online shopping experience (Jones and Suh 2000; Pu and Chen 2010). Compared to the Non-HPI environment, the HPI environment provides a rich experience with the products through haptic weight and texture evaluation. Such an experience is greatly influenced by the effectiveness and efficiency of the environment. The more effective and efficient the environment, the more satisfactory user ratings it will receive (Nielsen and Levy 1994). Hence, it is it is reasonable to assume that the HPI environment will have a positive impact on the user preferences and experience ratings as a result of better performance. Therefore, the following hypotheses are proposed.

Hypothesis 5: Subjects will find the haptic weight and texture features in the experimental HPI environment more helpful in comparison with the Non-HPI environment for selecting a product, in terms of product information.

Hypothesis 6: The experimental HPI environment's overall satisfaction ratings will be higher in comparison with the Non-HPI environment.

Hypothesis 7: Usefulness of the product information ratings in the experimental HPI environment will be higher in comparison with the Non-HPI environment.

Hypothesis 8: The experimental HPI environment ease of use ratings will be higher in comparison with the Non-HPI environment.

Hypothesis 9: Confidence in shopping decision ratings based on the product information in the experimental HPI environment will be higher in comparison with the Non-HPI environment.

5.6 Experimental Method

The experiment was conducted as a counterbalanced within-subjects experiment design using a 2 × 2 (interaction × task) Latin square. Subjects were randomly assigned to groups of equal size, and they were asked to perform two different shopping task scenarios using two different haptic shopping environments (i.e., Non-HPI and HPI), with one task for each system. Each group of subjects had a certain order of exposure to the systems and task assignments, but they were unaware which group they had been placed into, as illustrated in Table 5.5. Such a design is necessary to avoid biased results due to learning effects.

Subjects	First Condition		Second Condition	
Group 1	Non-HPI	Task 1	HPI	Task 2
Group 2	Non-HPI	Task 2	HPI	Task 1
Group 3	HPI	Task 1	Non-HPI	Task 2
Group 4	HPI	Task 2	Non-HPI	Task 1

Table 5.5: Assignment of systems and tasks for each subjects group.

5.6.1 Tasks

All subjects were asked to complete a training task before starting the experimental tasks (see section 5.6.1.2). The training task was provided to help subjects in learning how to use the device to interact with various interface functionalities in order to perform the main experimental tasks.

5.6.1.1 Training Environment Task

The purpose of the training environment was to allow subjects to practise the needed skill of moving the device stylus in all directions, where trial and error was encouraged to overcome any uncertainty some subjects might experience when first using haptic devices. The environment also allowed subjects to experience different types of buttons in the environment. No haptic properties were rendered at this stage other than the ability to hit the virtual environment side walls and click the virtual keypad buttons (see Figure 5.10).

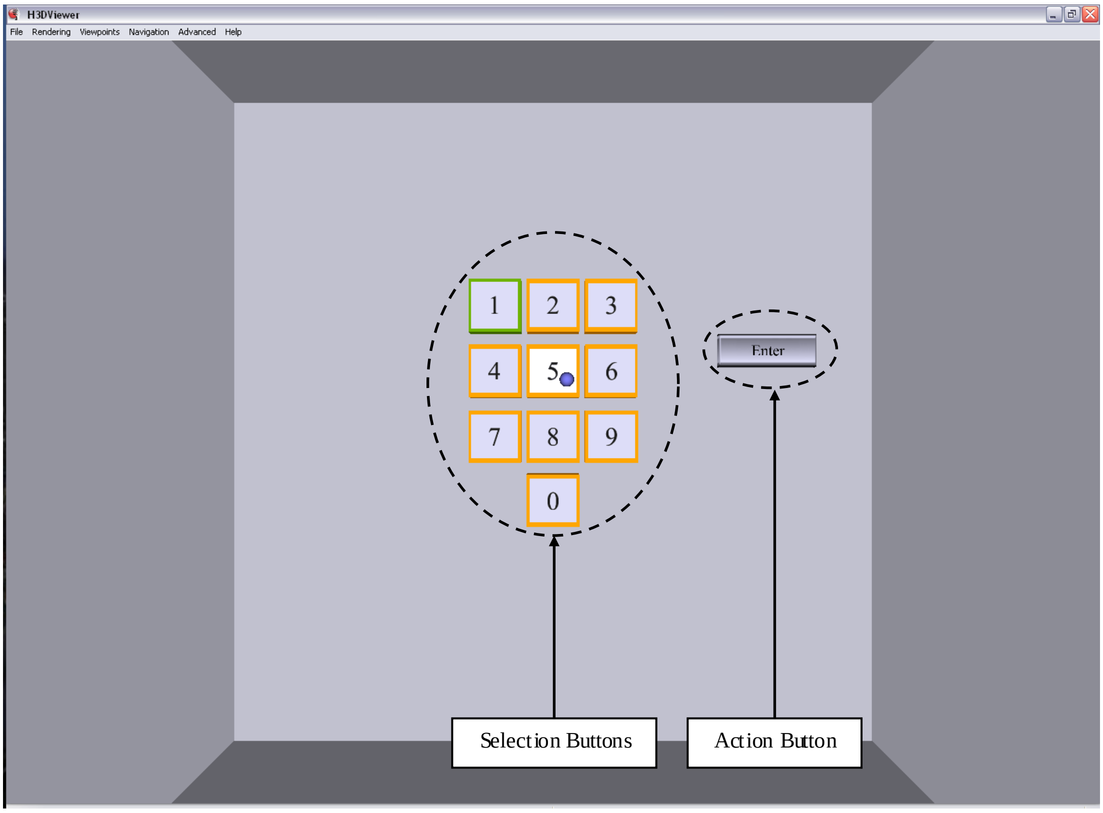


Figure 5.10: Training environment using virtual keypad.

The training task consisted of a virtual keypad displaying ten numbers, from 0–9. Subjects were asked to use the haptic feedback device to select predefined combinations of five numbers that were read out by the evaluator. To select a number, subjects had to first touch the number on the screen and then press the device stylus button. A touched number glowed brighter than the other numbers, and a selected number displayed a green square around it. Once all five numbers had been selected, subjects were asked to press “Enter.”

In order to pass the training session, subjects had to perform this task within 20 seconds. Subjects were not aware of this time limit at the beginning of the session. However, if they failed, a message was displayed that informed them how long they had taken and the time required to perform the task successfully. A new combination of five numbers was read out for each repeated trial.

5.6.1.2 Experimental Environment Tasks

In order to perform the experimental evaluation, two test task scenarios were constructed, with each presenting a specific exploratory task. Test tasks used in this experimental evaluation were formulated to be open in order to test different circumstances where some level of device features are expected (Carmel et al. 1992; Hoeber and Yang 2006). Test task scenarios were designed to not favour a particular product, but rather to motivate shoppers to use the systems in the manner intended (i.e. products comparison). Subjects were encouraged to explore and compare products freely in the interface, avoiding any particular comparison criteria. The theme was sports in both task scenarios, since massagers are often linked to this type of genre (McDonagh et al. 2005). Subjects had to accomplish each test task within criterion time (i.e. no more than 7 minutes), which had been estimated through piloting (see section 5.6.2). The task scenarios were as follow:

1. Assume that you are going hiking in the mountains for a week. One of the major concerns you are worrying about is muscle pain, especially on the early days. You are thinking of buying a massager to carry while hiking.

   Based on your opinion, use the system to "add to basket" one massager of your choice that best fits the scenario above.

In the first test task, subjects were expected to make choices that were more relevant to hiking activity needs. Since hiking is an outdoor activity that involves walking, the choice of device should at least ensure a chargeable power feature. However, among the devices that have this feature, subjects are expected to examine other features such as weight, feel, dimensions, and price.

2. Assume that you work at a fitness centre in the UK. Your employer noticed a shortage in the number of massagers available for adult members. He has suggested that you order one massager for adult members.

   Based on your opinion, use the system to "add to basket" one massager of your choice that best fits the scenario above.

In the second test task, subjects were expected to make choices that are more relevant to the fitness centre needs. Since this is an indoor activity that is provided by fitness staff members to satisfy the needs of a wide audience, the choice of device should at least ensure various levels of intensity feature. However, among the devices that have this feature, subjects are expected to examine other features such as weight, feel, dimensions, and price.

5.6.2 Piloting

Prior to administering the experiment, two pilot tests were conducted to reveal inconsistence or weaknesses in the evaluation plan. The pilot test was used to refine tasks scenarios and instructions, and to improve the experimental procedure and questionnaires. It was also used to evaluate and redesign the experimental environments (Nielsen 1993, pp.174 - 175).

For instance, the first piloting yielded problems in the interface design, which could have posed interaction problems if it had not been handled properly. The piloting was conducted using four student subjects, a male and a female who were colleagues, and another male and female who were invited. Subjects found it hard to locate the weight sliders and the texture surface using colour-coded asterisks (see Figure 5.11). They were concentrating on holding and stroking the respective colour-coded asterisk instead of the weight sliders and the texture surface functionalities. The colour-coded asterisks were replaced with suitable instructional messages, which were positioned under each haptic weight and texture functionality. Moreover, weight sliders were positioned at a higher point to make subjects aware of the full potentials of the functionality. The original low positioning of the weight sliders made subjects use them at a low point most of the time (refer to section 5.4.1 for the current design).

A second piloting to explore further inconsistencies or weaknesses in the evaluation plan was run. This piloting was conducted using different four students subjects (two male), which showed that the interface design and experimental procedure were now easier to follow. The pilot was used to set the session time, in this case, 7 minutes.

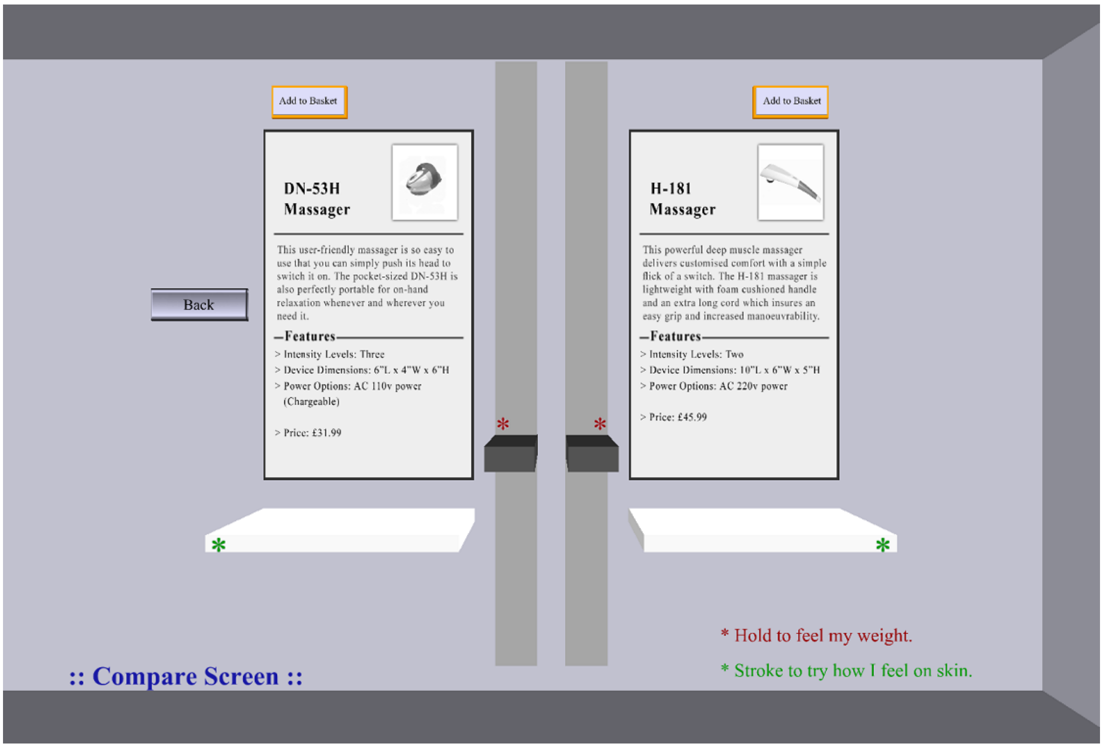


Figure 5.11: A discarded “Compare Screen” interface design due to usability issues.

5.6.3 Subjects

The number of recruited subjects in the present study not only meets the requirement of quantitative studies (Nielsen 2012), but it actually exceeds the sample size of most other usability studies in haptic systems (Khan et al. 2011b). In their review of 16 usability studies in haptic systems, Khan et al. (2011b) identified 13 studies that were conducted with less than 24 subjects, two studies that were conducted with more than 24 subjects, and one that was conducted with 24 subjects.

Recruitment was carried out largely through email and by placing posters around the university campus. Prospective subjects were emailed a link containing a self-reporting pre-session questionnaire to collect demographic details on the background and experience of the subjects (see Appendix E). Using opportunity sampling, Twenty-four paid (at five sterling pounds each) adults successfully participated in the study (divided equally by gender). All were students at Durham University, from various faculties and degree programmes. Twelve were between the ages of 18 and 25, ten between 26 and 32, and the remaining two were between 33 and 39. The subjects were all regular Internet users who were familiar with shopping online. Out of the total sample, nine reported playing 3D videogames (e.g., Doom, Quake, etc.). One reported using a 3D headset device to interact with virtual objects, but stated only novice experience.

5.6.4 Procedure

Subjects were welcomed by the experimenter and were guided to the lab. They were asked to take a seat in front of the computer, where they were introduced to the purpose of the study. Figure 5.12 shows the introduction script, which was verbally given to draw the attention of the subjects. Reading from the paper was avoided so that the procedure would not become perfunctory.

> This activity is intended to evaluate new shopping environments. We have solicited your help because we need an independent view of how well the systems operate. Your role is to perform tasks and fill-out questionnaires relating to the system in use.
>
> You will experiment with two systems. Please read the task scenarios carefully, which will be given to you shortly, and try to find an appropriate product based on the product information. The task ends when you add a product to basket.
>
> Training will be given before you start the actual experiment. The aim of the training is to familiarise you with the input device in preparation for the actual experiment tasks.

Figure 5.12: Introduction script to the experimental environments.

Upon agreement from the subjects, they were asked to sign the consent forms (see Appendix F). After brief handling instructions for the device and the training environment, a short training session was then carried out. This was to make sure the subjects had the necessary knowledge to operate the environment before they were exposed to the experimental environments and task activities.

After the training session, subjects were given the tasks sheet. An identical script was used to introduce the experimental tasks to the subjects (see Appendix G). The introductory script did not describe the steps needed to order a massager, but rather to further explain the sequence of the experimental procedure because one of the purposes of this research was to measure usability of the enhanced experience. Subjects were asked to use both systems (see Figure 5.13). The tasks consisted of selecting a product using the given system. Subjects could select any product and add it to a shopping basket, which marked the end process of a given task.

Figure 5.13: Haptic shopping experiment setup

At the end of each task, subjects completed a two-section self-reporting post-questionnaire on their experiences with and views regarding the system they had just used (see Appendix E). In the first section, using a checklist (Faulkner 2000, pp. 168 - 169), they were asked to tick which product information helped them the most to decide upon a specific product (e.g., weight, feel on skin, dimensions, power). This allowed for the comparison of the the evaluated systems. In the second section, single-item 4-point Likert scales, based on a modified version of the subjective experience level of usability evaluation (Lu and Smith 2008, 2010), were used. The decision to employ single-item measures was based on a study by Christophersen and Konradt (2010), which demonstrated that single-item measurements of online store usability is a useful measurement and a possible alternative to multi-item measures (e.g., SUS - System Usability Scale). Their study concluded that single-item measures are a reliable and valid type of measurement, and they allow shorter response time, hence lowering the frustration of the subjects that is often associated with multi-item measures.

The single-item 4-point Likert scales requests subjects overall satisfaction, usefulness of information, ease of use of the system, and confidence in buying decision to evaluate each system as objective reflection of their subjective satisfaction levels towards both shopping environments. While completing the task, time, product selection and button-click records were logged by the system in the background to evaluate each user's performance.

Each subject took between 40 and 50 minutes to complete the entire procedure, which was video-recorded. The video data were supplemented by observation by the experimenter. Note-taking was carried out to record the subjects' interactions and, or any other event that may not have been captured by the video-camera. Ethics approval was granted by the School of Engineering and Computing Sciences Ethics Committee at Durham University.

5.7 Statistical Analysis

In order to examine the difference between the Non-HPI and the HPI systems, nonparametric statistical measures were employed to analyse the continuous variables. This is due to concerns regarding the fact that assumptions of normality, which are required for parametric measures, were not satisfied (see Appendix H). McNemar's uncorrected chi-square test was applied to test the significance of the dichotomous variables produced by the first section of the post-questionnaire (i.e. which product information helped you the most in your selection?). An uncorrected test was considered, due to the unresolved dispute regarding the Yates correction, which suggests that it is excessively conservative, even in small sample sizes (Larntz 1978; Camilli and Hopkins 1979; Thompson 1988). Moreover, due to the many tied ranks often associated with the limited ordinal range of Likert scales (e.g., the four-point Likert scale), a Sign test was performed to generate a more accurate calculation of the significance probability values (i.e., *p*-value), as suggested by Roberson et al. (1995), for the second section of the post-questionnaire, which consisted of four items on a four-point Likert scale to measure subjects' satisfaction opinions. This was to compare the difference between each subject's ratings of overall satisfaction, usefulness, ease of use, and confidence in the shopping decision. Furthermore, the time spent on tasks, the button clicks, and the subjects' product selection, which were obtained from automated system logging, were analysed using a Wilcoxon Signed Ranks test to quantitatively identify significant differences between the two experimental environments.

5.8 Results

The result section begins by highlighting the results of the training that the subjects underwent as a prerequisite to the experimental evaluation. This is followed by a detailed experimental results analysis based on the three usability criteria: effectiveness, efficiency, and user satisfaction. The interpretation of the results is given in section 5.9.

5.8.1 Training Results

All 24 subjects successfully completed the training session. Subjects needed at least three trials to successfully pass the training session (see section 5.6.1.1). In the first trial, 11 subjects passed with an average time of 15.6 seconds (SE = 0.67). In the second trial, 12 subjects passed with an average time of 15.5 seconds (SE = 0.69). In the third trial, only one subject needed 19 seconds to pass the training session.

5.8.2 Experimental Results

The experimental sessions were also successfully accomplished by all 24 subjects. System logs and questionnaires were analysed based on the hypotheses (see section 5.5) regarding the effectiveness, efficiency, and user satisfaction of the shopping environments (Non-HPI and HPI). It is also worth noting at the outset that, at the completion of the HPI environment tasks, on average, subjects made 6.54 (SEM = 1.11) haptic product weight trials and 5.83 (SEM = 0.95) haptic product texture trials. Considering that there are only six products available to explore, the average number of trials for each haptic feedback function is almost equal to the number of available products. This is relevant because it shows that subjects tended to use the haptic weight and texture feedback functions often to evaluate their product preference, thus allowing for a reflective interpretation of the effectiveness, efficiency, and user satisfaction of the shopping environments.

5.8.2.1 Effectiveness

The effectiveness of the haptic product information in comparison to the textual product information system was examined. Effectiveness was measured (through automated system logging) in terms of the rate of accomplishing the assigned tasks successfully within a given time-frame and the quality of the selected products output for the accomplishment of the assigned tasks.

The success rate for accomplishing the tasks was 100 percent. All subjects completed the two tasks within the 7-minute timeframe (see section 5.6.1.2). A task was considered successfully completed when all functionalities had been utilised within a given system environment. Subjects were not given any assistance while browsing the environments, and they were free to make any decision during the experimental tasks. Thus, research hypothesis 1 (i.e., the experimental HPI environment will be similarly effective in comparison with the Non-HPI environment in terms of the rate of accomplishing the assigned tasks successfully within a given timeframe) cannot be rejected.

Figure 5.14 and 5.15 show the selected products' output for the accomplished tasks in the Non-HPI and HPI environments. In task 1, product M3 was selected 83.33 percent of the time in the Non-HPI environment, while it was selected only 66.67 percent of the time in the HPI environment. There is a slight shift in product selection towards product M2 for the HPI environment, which was not the case in the non-HPI environment. In task 2, the selections tended to spread between multiple products. Products M4 and M5 received the highest selections, with 58.33 percent for the non-HPI environment and 66.67 percent for the HPI environments. A test of effect analysis indicated no significant difference between the non-HPI and HPI environments in both tasks in terms of the selected products output (p > .5, Wilcoxon Signed Rank test). Thus, research hypothesis 2 (i.e., the experimental HPI environment will show dissimilar output quality in comparison with the Non-HPI environment in terms of the products selected for the accomplishment of the assigned tasks) is rejected.

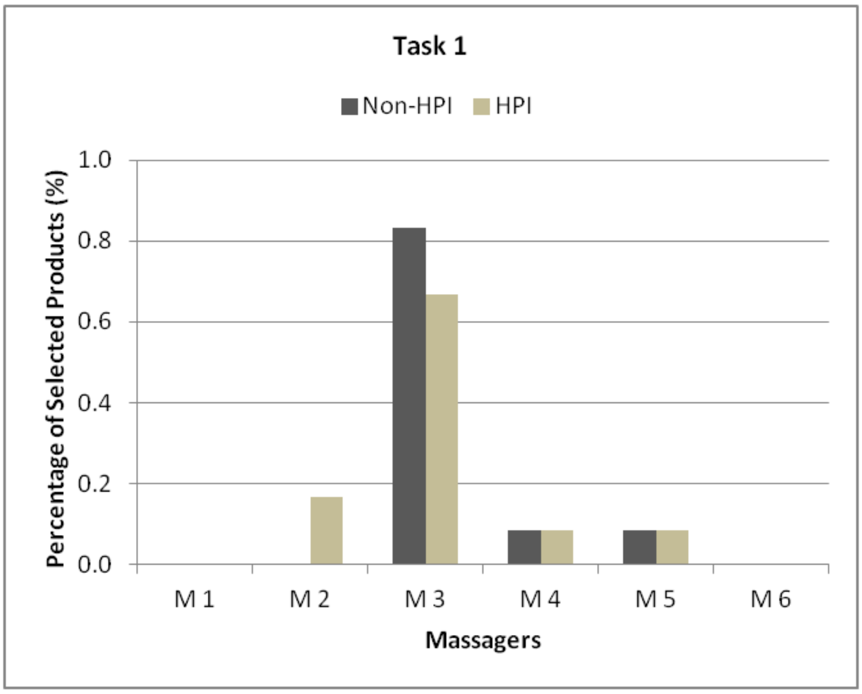


Figure 5.14: Subjects' selected products for task 1. No significant difference between the Non-HPI and HPI environments in terms of the selected products output (p > .5, Wilcoxon Signed Rank test). Refer to Table 5.1 and Table 5.2 for products information.

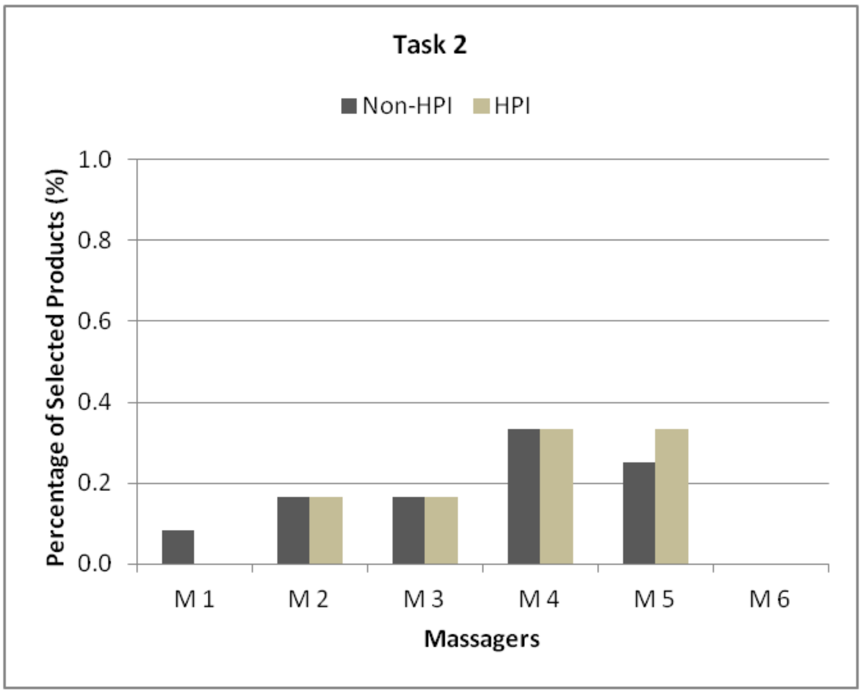


Figure 5.15: Subjects' selected products for task 2. No significant difference between the Non-HPI and HPI environments in terms of the selected products output (*p* > .5, Wilcoxon Signed Rank test). Refer to Table 5.1 and Table 5.2 for products information.

5.8.2.2 Efficiency

The efficiency of the haptic product information in comparison to the textual product information system was examined. Efficiency was measured (through automated system logging) in terms of the time spent for the accomplishment of the assigned tasks, and the number of actions required to accomplish the assigned tasks.

Figure 5.16 shows the time spent to accomplish the tasks for the Non-HPI and HPI environments. In both tasks, the average time spent tends to increase in the HPI environment. In task 1, on average, subjects spent about 2 minutes and 30 seconds in the Non-HPI environment, while they spent around 3 minutes and 40 seconds in the HPI environment. Likewise, in task 2, subjects spent on average just little over 2 minutes and 30 seconds in the non-HPI environment, but almost the same amount of time as they did on task 1 in the HPI environment. However, a test of effects analysis indicated no significant difference between the Non-HPI and HPI environments for either task in terms of the time spent ($p > .5$, Wilcoxon Signed Rank test). Thus, research hypothesis 3 (i.e., the experimental HPI environment will be similarly efficient in comparison with the Non-HPI environment in terms of the time spent for the accomplishment of the assigned tasks) cannot be rejected.

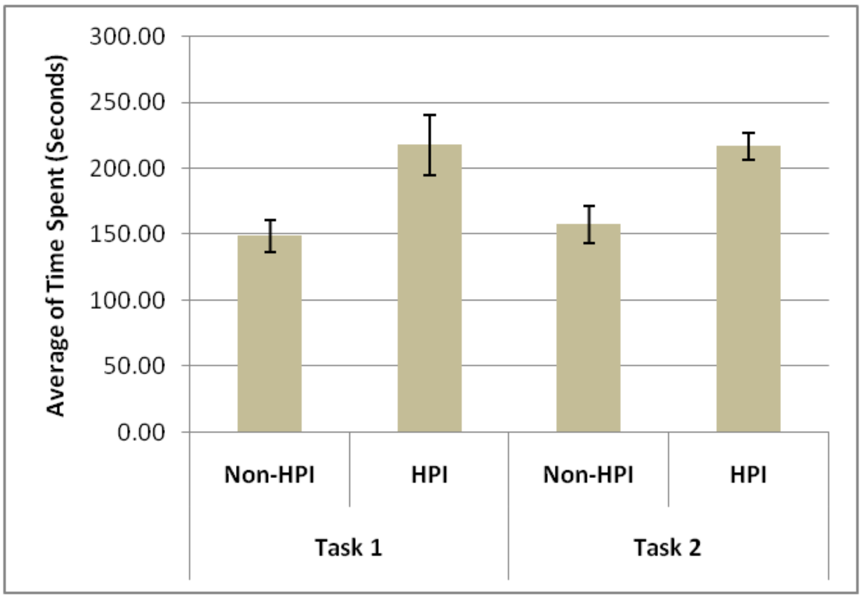


Figure 5.16: Subjects' time spent on task 1 and task 2. No significant difference between the Non-HPI and HPI environments in terms of the time spent for both tasks ($p > .5$, Wilcoxon Signed Rank test).

Figure 5.17 shows the number actions required (i.e., number of "Compare" and "More Info" button clicks) to accomplish the tasks for the Non-HPI and HPI environments. As envisaged, there is a reduced number of actions required in the HPI environment. For both tasks, the average number of clicks required was close to 5 in the Non-HPI environment. On the other hand, subjects required, on average, just little below 4 clicks when they used the HPI environment in task 1, while they required exactly 4 clicks in task 2. However, contrary to expectations, a test of effects analysis indicated no significant difference between the two environments for either task in terms of the number actions required to complete the assigned tasks (*p* > .5, Wilcoxon Signed Rank test). Thus, research hypothesis 4 (i.e., the experimental HPI environment will be more efficient in comparison with the Non-HPI environment in terms of the number of actions required to accomplish the assigned tasks) is rejected.

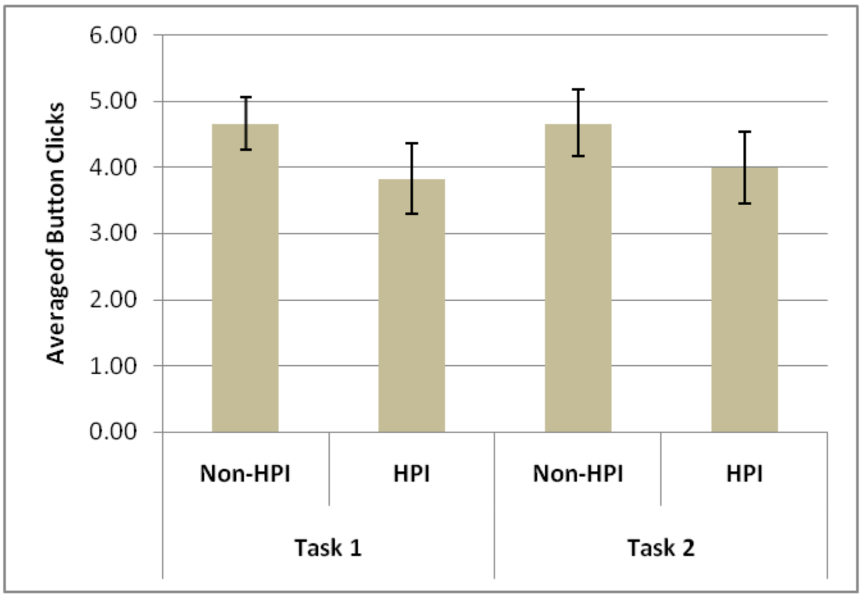


Figure 5.17: Subjects' number of actions required (number of "Compare" and "More Info" button clicks) on task 1 and task 2. No significant difference between the Non-HPI and HPI environments in terms of actions required in either task (*p* > .5, Wilcoxon Signed Rank test).

5.8.2.3 User Satisfaction

The efficiency of the haptic product information in comparison to the textual product information system was examined. Satisfaction was measured (through a questionnaire) by subjects' opinions regarding which product information helped them the most in their selection, as well as their ratings of their overall satisfaction with the systems, the usefulness of the product information provided, system ease of use, and their confidence level in their shopping decision, based on the product information.

In the first section of the post-questionnaire, subjects were asked, “Which product information helped you the most in your selection?” They were asked to tick all that applied from a list of choices. The intention of this question was to find out which product information was most helpful in their decision to choose a particular product. Figure 5.18 shows subjects’ opinions regarding the product information in the Non-HPI and HPI environments regarding what helped them the most in their shopping selections for Task 1. The results revealed the dominance of weight, with 83.33 percent in both environments, while price and image are variable, at around 41.67–66.67 percent, depending on the environment. However, a test of effects analysis indicated no significant difference between the Non-HPI and HPI environments in terms of the helpfulness of the product information ($p > 0.05$, McNemar test). Thus, research hypothesis 5 (i.e., subjects will find the haptic weight and texture features in the experimental HPI environment more helpful in comparison with the Non-HPI environment for selecting a product, in terms of product information) is rejected for task 1.

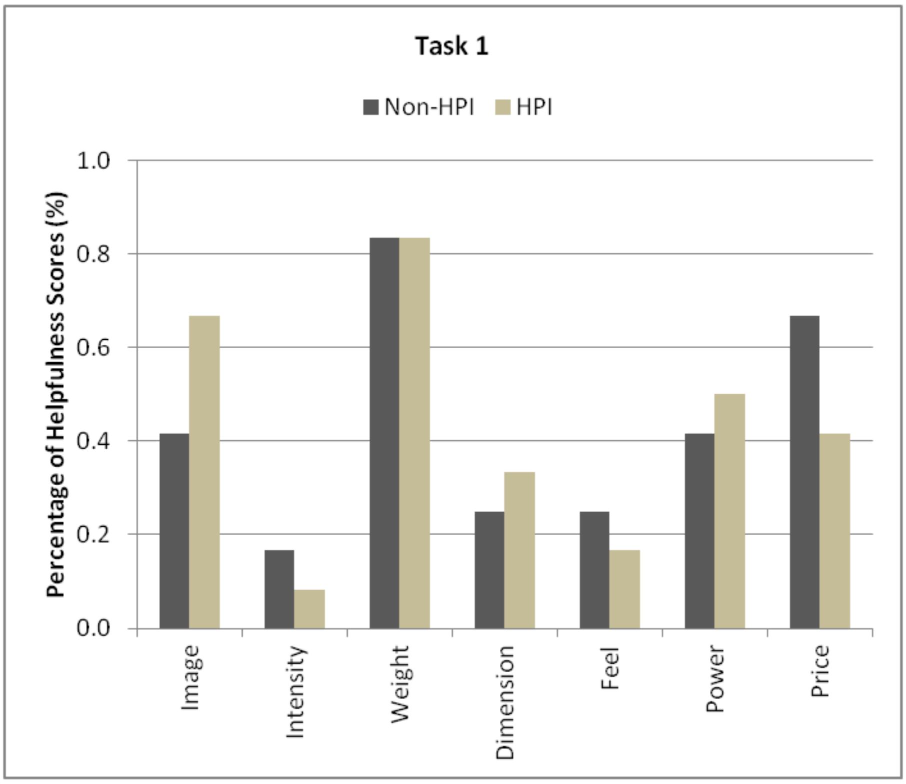


Figure 5.18: Average subjects' opinions of the product information that helped them the most in their selection for task 1. No significant difference between the Non-HPI and HPI environments in terms of product information helpfulness ($p > .5$, McNemar test).

On the other hand, Figure 5.19 shows a comparison between Non-HPI and HPI environments regarding the product information that helped them the most in their shopping selection for Task 2. The HPI environment results revealed the dominance of weight, at 91.67 percent, followed by feel and price, with 66.67 percent each. In contrast, the Non-HPI environment results showed a stronger tendency towards price (66.67 percent), followed by product image, with 50 percent. Indeed, statistical comparisons between the environments reveal a significant increase in the HPI environments in terms of the helpfulness of the weight ($p < 0.01$, McNemar test) and texture ($p < 0.05$, McNemar test) product information. Thus, research hypothesis 5 cannot be rejected for task 2. Moreover, power options information appears to have also shown a statistically significance decrease ($p < 0.05$, McNemar test) as helpful information for product selection.

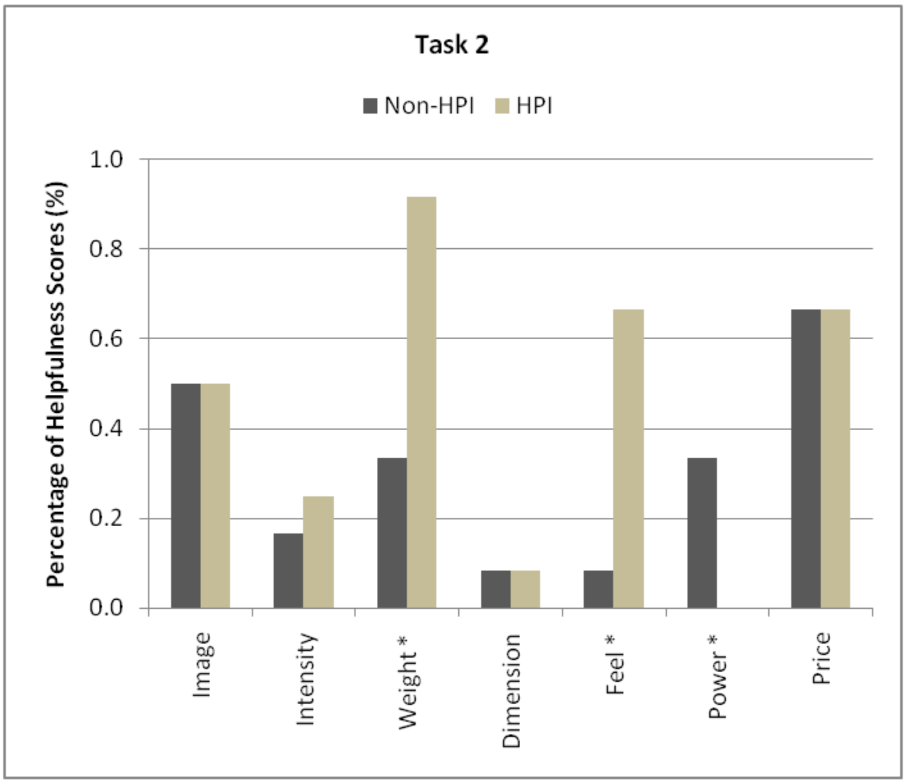


Figure 5.19: Average subjects' opinions of the product information that helped them the most in their selection for task 2. There is a significant difference between the Non-HPI and the HPI environments in terms of product information helpfulness for weight* ($p < 0.01$, McNemar test) feel* ($p < 0.05$, McNemar test) and power* ($p < 0.01$, McNemar test) information.

In the second section of the post-questionnaire, subjects were asked to rate four items of a four-point Likert scale concerning their overall satisfaction with the system, the product information usefulness, the system's ease of use, and their confidence in their shopping decision. The purpose of these questions was to measure the subjects' satisfaction opinions about the Non-HPI and HPI shopping environments for each shopping task. Figure 5.20 shows the four satisfaction items ratings for task 1, based on subjects' opinions. On average, the satisfaction with the system and the usefulness of the product information items tend to increase when using the HPI environments, while the system's ease of use and the confidence in the shopping decision tend to also increase but with smaller margin. However, a test of effects analysis indicated no significant difference between the Non-HPI and HPI environments on any satisfaction item ($p > 0.05$, Sign test). Thus, research hypotheses 6, 7, 8, and 9 (see section 5.5) are rejected for task 1.

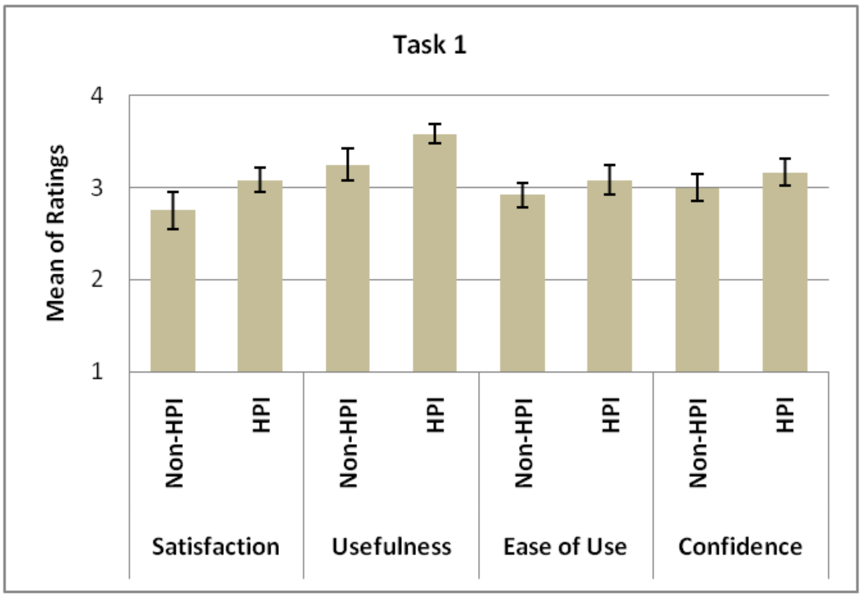


Figure 5.20: Subjects' satisfaction opinion regarding the Non-HPI and HPI shopping environments for task 1 (1 = Very Negative, 4 = Very Positive; see Appendix E). No significant difference between the Non-HPI and HPI environments on any satisfaction item ($p > .5$, Sign test).

Figure 5.21 shows four satisfaction item ratings for task 2. On average, satisfaction with the system tends to increase when using HPI environment, while system ease of use tends to decrease. Usefulness of the product information provided hovers just around the 3-point rating mark for both shopping environments. However, the confidence level in the shopping decision increased considerably, indicating higher confidence, with the HPI shopping environment. Statistical comparisons between the environments yield a significant increase in the subjects' confidence ($p < 0.05$, Sign test) when using the HPI environment. Thus, research hypothesis 9 (i.e., confidence in shopping decision ratings based on the product information in the experimental HPI environment will be higher in comparison with the Non-HPI environment) cannot be rejected for task 2. All other items showed no significant results; thus, 6, 7, and 8 are rejected.

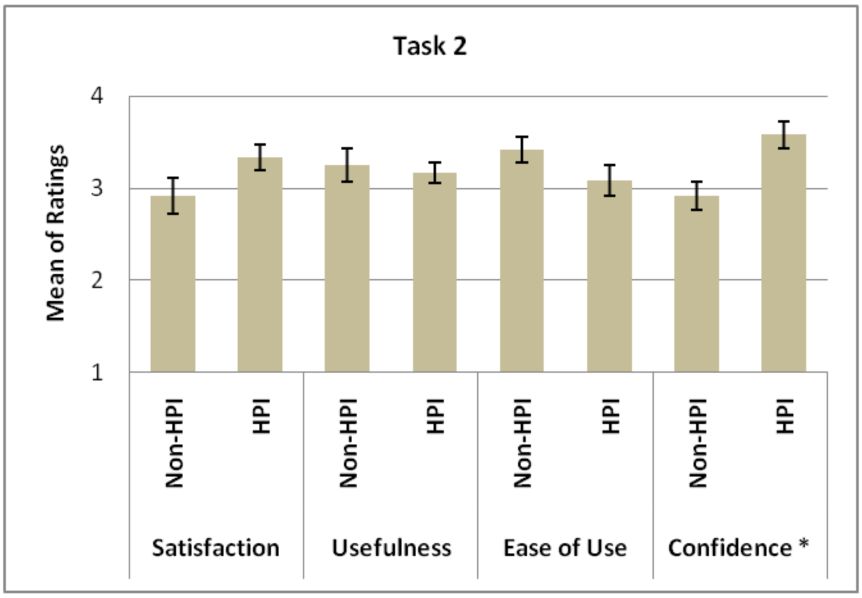


Figure 5.21: Subjects' satisfaction opinion regarding the Non-HPI and HPI shopping environments for task 2 (1 = Very Negative, 4 = Very Positive; see Appendix E). There is a significant difference between the Non-HPI and HPI environments in shopping decision confidence* (*p* < .5, Sign test).

5.8.3 Observation and Subjects' Comments

Besides observation, some other subjective questions were asked in the questionnaire to collect more feedback and suggestions from subjects (see Appendix E). Overall, subjects did not feel there were too many barriers to using this type of technology, and they were able to interact with the environments as they intended. However, two subjects expressed concerns about interaction tiredness after a using the haptic feedback device as a replacement for mouse interaction.

Subjects' feedback consistently showed interest in the haptic product information, especially the ability to haptically experience products' weight. Subjects' comments included: "I could see myself using this in the future," "It makes virtual shopping a more realistic experience," and "I was very impressed by the weight function." When trying haptic products' weights, subjects had also expressed interest through behavioural expressions such as stating, "Clever" and "Cool," smiling, and opening their mouths (Kaliouby and Robinson 2005).

On the other hand, the ability to haptically experience products' texture seemed to bring up some critical points to consider. One of the subjects suggested that it is hard to envisage the feeling of the massager only through the use of the hands: as noted in the subject's feedback, "People still want to know how it feels on the part of the body that needs massaging," Such a suggestion, while important, is not substantial, since many online products (e.g., apparel) are often sold without physical inspection by consumers. Consequently, the limitation of current haptic technology should not restrain the application of available advanced technology in online shopping.

Another interesting observational finding was related to the haptic product information trial sequence. At the "Compare Screen" (see Figure 5.8), almost all subjects followed the same pattern when comparing the haptic weights and textures of different products. They had a tendency to compare each haptic property separately, rather experiencing the haptic properties of one product and comparing them to another product. Moreover, graphical interface observation had given the impression that three-dimensional buttons engendered a navigational inconvenience, especially when there were many buttons. This is true at the "Home Screen," where subjects tended to accidently hit the "More Info" and "Add to Compare" buttons when moving around the screen. Subjects had a tendency to stay at their *z*-axis position when moving between buttons. This happened quite often at the beginning of the session, but then faded away as they became accustomed to the activity. Such observations might pose a challenge to online shopping haptic designers, who might need further investigations to ensure optimum haptic shopping experience.

Observational notes and user comments focused equally on the desire for more engagement through the use of larger images or a greater ability to manipulate a combination of different haptics, for instance, 3D images of products with integrated haptic properties. One subject's feedback suggested, "If there were 3D pictures (in real size) it would help as well." Although this was not possible with the current HPI system, due to the design choices made, attempts to hold the weight and feel the surface texture at the same time were evident.

5.9 Chapter Summary

This chapter has documented an experimental evaluation to investigate the usability haptic feedback interaction to enhance online shopping. Previous studies have shown that haptic feedback has the potential to enhance the overall performance and user experience of a broad range of applications, such as education and training, entertainment, industry and engineering, and marketing (see section 2.4.4). However, there is a dearth of published information about the potential of using haptic feedback interaction in online shopping. Such an enhancement may be advantageous and could promote more people to join in the B2C e-commerce websites.

The investigation was undertaken to shed light on the usability of using haptic product information to convey weight and texture (i.e., HPI) compared to an environment based entirely on textual product information (non-HPI). The investigation focused on three aspects identified by the ISO: effectiveness, efficiency, and user satisfaction. The metrics used to measure effectiveness were rate of accomplishing the assigned tasks and the quality of the output, while efficiency was measured in terms of time spent and the number of actions required to accomplish the assigned tasks. To evaluate each environment, user satisfaction was measured using single-item, four-point Likert scales regarding overall system satisfaction, usefulness of product information, system's ease of use, and confidence in the buying decision.

Given that the shopping environments were developed as an initial prototype to evaluate haptic product information as a primary goal, this study showed extremely promising results with respect to the usability of haptic shopping. Even with a brief training session, subjects were able to interact productively with the Non-HPI and HPI environments using the haptic feedback device, despite their inexperience. All subjects were able to complete both experimental tasks successfully within 7 minutes. Subjects utilised all functionalities available in both environments with a 100% completion success rate. In the HPI environment, they carried out an average of approximately 12 haptic product information trials (i.e., about six haptic product weight trials and six haptic product texture trials) before they selected a product. Weight trials were counted as successful when subjects moved the slider to weigh products, while successful texture trials were calculated when subjects touched and explored the texture surface. The haptic product information did not seem to add any level of difficulty to the interaction.

Comparison between the Non-HPI and HPI environments in terms of product selection output quality, dissimilar selection was not evident. Subjects' product selection in the Non-HPI environment had similar patterns to those of the HPI environment, which indicates that their selection was not entirely based on the product haptic information, but that other common factors such as price and appearance were considered (Kabecha 1998; Creusen and Schoormans 2005). This is evident in the subjects' opinion of the product information that helped them the most, where haptic information, as well as product price and appearance, played a role in their selection for task 1 (see Figure 5.18) and task 2 (see Figure 5.19).

In task 1, which offered the hiking scenario in which a chargeable power option was important (see section 5.6.1.2), subjects' choices were limited to massagers M2, M3, and M6, since they were the only massagers that were chargeable. While 16.66 percent of the subjects incorrectly selected the M4 or M5 massager choices in this task using both the Non-HPI and the HPI environments, the majority of subjets selected product M3, which is lightweight and small, which fits the purpose of going hiking. However, despite its highly similar attributes, and its advantage of having a better feeling on the skin, M6 was not selected in either environment, as it is somewhat more expensive (i.e., £4 difference) and is slightly bigger than M3. This may be because subjects did not feel that the advantage of a better feeling on the skin justified spending extra on a device that would be used only occasionally (i.e., during hiking), and its larger size might add more bulk and take up extra space when carrying it.

On the other hand, task 2 (see section 5.6.1.2), which offered the fitness centre scenario, where a variety of levels of intensity was important, subjects' choices were limited to massagers M1, M4, and M5, since they are the only massagers that provide more intensity levels to satisfy the needs of a wider audience. Despite the fact that 33.34% of the subjects selected the incorrect M2 or M3 massagers for this task in both environments, the M4 and M5 massagers were a majority in terms of the frequency of selection amongst subjects, at 58.33 percent of selections in the Non-HPI environment and 66.66 percent of selections in the HPI environment, when compared to the M1 massager. Although the M1 massager was cheaper than M4 and M5, its small appearance, as well as its heavy weight compared to its size, could have suggested that staff members might have difficulty handling it, and this may have made subjects turn away from it.

The results of the time spent carrying out both tasks showed significant similarity between the Non-HPI and HPI environments, as hypothesised. This is in line with the previous research discussed in section 2.4.4, which has found that haptics have no effect on reducing task times (Oakley et al. 2000; Yu and Brewster 2003). In fact, the task timing performance in this experiment tends to increase when using haptic evaluation, which contradicts other research that has claimed a reduction in performance time (Miller and Zeleznik 1998; Krol and Aliakseyeu 2009). One potential reason for the tendency for performance time to increase is the need to explore the environments (Wood et al. 2003). The nature of the shopping tasks that require subjects to explore the environments and evaluate haptic weights and textures could account for the slight increase in the time spent. In the Non-HPI environment, subjects could just read what was presented with no evaluation, while in the HPI environment; subjects had to haptically evaluate the products, as well as read about the other features. The combination of reading and haptically evaluating products could have required that subjects take slightly more time.

However, although not significant, such a tendency for performance time to increase has produced a reduction tendency in button clicks before a product of choice is selected in both tasks. Since dissimilar product selections were not evident between the environments, it is relevant to suggest that haptic product information seems to enhance the evaluation effort required before a product is selected. Nevertheless, further work is needed on this point, as it may have been that the extra time spent on haptic information was making subjects give up comparing products earlier than they should have and depend on using clues other than the haptic information to suggest an appropriate device for the task, such as price and appearance.

In terms of subjects' opinions regarding the product information that helped them the most in their product selection, as along with weight, price and image played a large role in their selection for task 1 (i.e., hiking task scenario) in both environments. However, the feeling on the skin rating was very low, as subjects seemed to be greatly influenced by the weight, price, and appearance to satisfy their needs. This explains the selection of massager M3, which was the lightest, cheapest, and the smallest in terms of shape. However, in task 2 (i.e., the fitness centre scenario), both weight and feel played a statistically significant role in helping product selection in the HPI environment compared to the non-HPI environment, which was confirmed statically. Although they played a role, their influence was not reflected in the subjects' selected products, as these were almost identical in both environments (see Figure 5.15). A possible explanation for this might be that providing haptic weight and feel added confidence to the decision, which does not necessarily impose a different choice of product. This was evident in the subjects' subjective satisfaction ratings; all items except confidence in the shopping decision based on product information showed no statically significant difference for this particular task.

In general, observation and subjects' comments, presented in section 5.8.3, suggested that the overall haptic shopping experience was favourable. When comparing the Non-HPI to the HPI environment, the subjects expressed interest in the HPI environment. However, subjects believed that there were some improvements that could be made to its design.

Chapter 6: General Discussion

6.1 Introduction

Chapters 3 and 4 of this thesis documented two initial psychophysical studies. The aim of these initial studies was to investigate the smallest haptic stimuli difference, or JND threshold, needed to effectively discern haptic weight and friction stimuli for an online shopping context. The JND threshold measurement seeks to provide a better understanding of the haptic device limitations in terms of the availability of different stimuli to represent physical products when shopping online. The knowledge gained from the two initial experiments on haptic weight and friction surface (i.e., texture) force discrimination helped to identify absolute haptic stimuli to represent products' weight and texture sensations for a follow-up study.

Chapter 5 of the thesis documented a third and final study that measured users' experience of haptic shopping. The aim of this study was to investigate the use of haptic feedback to enhance the online shopping experience. This is meant to augment the traditional textual representation of weight and texture product information with one that is conveyed through haptics. Alongside performance measures, subjective satisfaction experiences of the interactive shopping environment were collected to measure the enhancement effect. The following general discussion section is presented in light of the abovementioned studies.

6.2 General Discussion

Haptic feedback plays an important role when interacting with virtual objects. It allows users to manipulate and sense the properties of virtual objects, such as their weight and surface texture. Such technology can bring benefits to a broad range of applications, including, but not limited to, education and training, entertainment, industry and engineering, and marketing (Eid et al. 2007; Saddik et al. 2011c). In the context of online shopping, haptic technology may provide consumers with physical information about products without the need to visit the local store (Steinfield and Klein 1999) and may assist them in making a more informed product selection (Mooy and Robben 2002). However, in order to evaluate the usability of haptic feedback technologies to enhance the interaction of existing online shopping systems, there are a number of approaches that this research has undertaken to tackle various technical, operational, and economical issues.

One issue is relevant to the technology used in the study. Given that subjects had to a use haptic device to interact with the environments during the course of the research, the use of new technology to replace a 2D mouse-based interaction may have an effect on the findings obtained due to the users' unfamiliarity with the technology (Chirathivat et al. 2007). Unfamiliarity with the technology may make subjects focus on learning to use of the haptic technology rather than fulfilling the task needs. Unlike mouse-based interactions, haptic interaction requires free-moving in all axis directions to navigate the 2.5D haptic shopping environment. One way to avoid this is to provide subjects with appropriate training to use the technology. Throughout this research, subjects were trained to use the haptic feedback device in a dedicated environment before they start the actual experimental tasks. Such training is directed toward providing the necessary skills to navigate around the 2.5D space. However, as far as online shopping is concerned, the comparative study between the Non-HPI and the HPI shopping environments both utilised the same haptic feedback device. Although the Non-HPI environment consisted of only textual information which can be navigated using mouse-based interaction, utilising the some method of interaction in both environments was crucial in measuring the usability of the environments. Using a long established mouse-based interaction to navigate the Non-HPI environment could cause superior effect on the findings due to familiarity with the technology. Hence, a longitudinal study may offer a better evidence of the usability of such technology to replace mouse-based interaction in online shopping applications.

Another issue has to do with the prolonged use of the haptic feedback device in interaction. Although this was not plainly evident in this study, prolonged use of the haptic feedback may cause fatigue (Zhai 1998). One reason for this is the continuous need to hold the haptic feedback device stylus to interact with the environment. Unlike mouse-based interactions, the haptic feedback device requires 6 DoF movements in all directions, and every so often the activity includes resistive force. As a result, the research has ensured that the haptic feedback device was positioned at suitable range that allowed subjects to rest their arms on the desktop surface. Also, the experimental tasks in this study did not require subjects to continuously hold the haptic feedback device stylus while interacting with the haptic environments. In the shopping environments, for example, bursts of interaction with limited duration and limited haptic intensities (weight and texture) were carried out, where subjects could reset their hand while reading information or between each task. Hence, the impact of such fatigue on the usability of haptic technology to navigate and evaluate products is minimal. However, if the activity involves continuous holding of the haptic feedback device stylus for long periods or the use of exhausting feedback intensities, then there may be a need for a more user-friendly, intuitive device design. For instance, a mouse-like haptic feedback device (Choi et al. 2003), which allows for sufficient resting of the arm and hand on the desktop surface, could potentially eliminate fatigue and enhance the interaction requirements.

The third issue is related to the single-point interaction style used to interact with various experimental weights and textures during all phases of the present research. There is trade-off between using a multi-point haptic interaction, where sensations are conveyed to, for example, the human fingers or the whole arm, and a single-point haptic interaction. The ability to simultaneously grasp an object to feel its weight and touch a surface with a bare finger to explore its texture, that are normally performed when feeling and exploring real-world objects, can only be achieved through multi-point haptic interaction. While multi-point haptics may offer the advantage of examining object property information more naturally by resembling real-world physical interactions, such interactions may not be economically feasible, since they are typically overly expensive and/or complex (Ang et al. 2011). On the other hand, single-point haptic interaction devices, such as the Phantom Omni device and the Novint Falcon device, can offer high-fidelity haptic interaction, and are small, far less complex, and more affordable (Ang et al. 2011). If haptic-based shopping were to be adopted in the future, these advantages are likely to be among the characteristics of the ideal device. Single-point interaction devices may not be able to achieve real-world interactions (McKnight et al. 2005), but they are capable of providing enough haptic information to allow more informed shopping choices to be made.

The fourth issue is related to the user interface (UI) control design choices needed to evaluate haptic product information. Different haptic information to convey weights and textures was simulated in the work presented here. However, a single UI control to convey both haptic weights and textures information is difficult to implement due to the device limitation of single-point contact. While feeling haptic weight requires picking up an object, haptic texture requires a large enough surface space to allow it to be explored. Hence, using the texture surfaces to also convey weight is impractical, as it will constrain the visual view of other textual product information on the screen. One way to overcome this difficulty is to implement different UI controls for haptic information—one to convey the product weight and another to convey the product surface texture. In this way, haptic interactions are performed without interfering with the visual view, since the weight and texture controls have their own dedicated space. This design choice may have used up a great deal of the available visual space. In this research, the HPI environment, for example, has allowed only two products to be compared at a time, which required four haptic UI controls to evaluate weights and textures. The introduction of the four UI controls limited the space available for more comparisons to be performed. However, if more comparisons are a requirement, then a dedicated weight and texture comparisons screen that is detached from the main information screen or a different visual depth on the same screen may be used to accommodate both haptic and textual information of more than two products.

An additional issue is related to the realism of the haptic rendering in comparison to real-world information. The fact that haptic feedback experience in online shopping was the focus of this research has made the simulation of real-time realistic haptic information secondary to the work. Evaluating realistic haptic information may improve user perception of the online products, thus allowing products to be compared not only within the online store, but also between the online store and what the shoppers already possess. It can also improve the seller–buyer interaction by allowing common, real-world exchanges in real time, like, for example, allowing sellers to physically hand over different products to potential online shoppers. Although such improvement of haptic information may contribute to the overall user experience and extend its application to higher dimensional problems, the high computational cost associated with rendering and displaying realistic haptic information may make the technology time-consuming to develop and economically unfeasible for commercial use. A high volume of graphic and haptic processing may require the availability of extra hardware resources to run smoothly on the client's side. Servers that host the processing may also require extra hardware resources to be capable of processing the high volume of requested data. However, the vast majority of online customers may not have the minimum hardware requirements to be able to run such technologies. Also, businesses may not be willing to spend resources on upgrading their current servers. Furthermore, effective haptic interaction through a virtual shopping environment, where customers interact haptically in real time, is still difficult, due to internet technology limitations. The current internet technology suffers from network jitter and latency of the transmitted haptic data, which requires 1 kHz of refresh rate in order to achieve a rich interaction (Eid et al. 2007). While trade-offs between real-time realistic haptic information and technology cost exist, the present study has circumvented these trade-offs by concentrating on providing a relative impression of the product in question that is sufficient to enable non real-time comparisons to be made. This might not be dissimilar to the sort of visual impressions available in online shopping. Despite obvious differences in the quality and availability of product images across e-commerce websites, they play an important role in catching the users' attention (Lee and Benbasat 2003) and generating positive attitudes amongst users (Hong et al. 2004). It is probable that a cost-effective, real-time haptic feedback that provides an absolute impression of the product will arise in the future, but until then, the proposed interaction should serve to improve online shopping product evaluation.

The amount of simulated haptic information used to represent various products for comparison may also pose another challenge in adopting the technology. While the simulation of haptic weight and texture information is limited to what the haptic device is capable of providing, the number of comparisons that can be felt depends on human sensory perceptions (see section 2.2). Therefore, identifying haptic information that provides a consistent basis for comparison is essential, because it allows consumers to make well-judged choices. One way is to use psychophysical experiments to study users' perceptions of haptically simulated information. This study has made use of the psychophysical measurement method of constant stimuli and the method of transitions in order to easily and accurately estimate the smallest stimulate needed distinguish between two elements of simulated haptic information, formally known as the JND. As the shopping environment evaluation task scenarios were based on an experimental prototype containing a small number of virtual product comparisons, six virtual products in total, there was little need for extensive haptic information simulation JND measurement. However, if the task scenarios required users to evaluate haptic information of various products with wider categories (e.g., heavier weights, deformation, and roughness properties), which could require different device to simulate, then there would be a requirement for further psychophysical measurement, such as those adopted in this study. Such a method can be easily applied to other types of haptic properties and devices just by adjusting the perceptual stimuli in question. This includes not only the tactile and kinaesthetic simulations, but also extends to other forms of simulations in which haptic simulations are combined with other visual and graphical information. For example, estimating the JND by using different object sizes (Hara et al. 2004) or motion speeds (Dominjon et al. 2005) to create the illusion of different haptic weights or by mapping a graphical representation on the surface texture to express different texture properties (Luo and Imamiya 2003).

Moreover, providing a complete a list of absolute haptic weight and frictional texture stimuli based on the identified JNDs threshold was of concern. Although the observed JNDs were of assistance on deciding the absolute haptic stimuli to represent products' weight and texture sensations, as discussed in section 5.4.2, further psychophysical studies maybe necessary to evaluate other standard haptic stimuli bases, especially those with lighter stimuli intensity (see sections 3.5.2 and 4.5.2). This is because light stimuli intensities require higher JNDs in order to be sensed by human subjects, as suggested by Engens (1971, as cited in Gescheider 1997). This requirement was not achievable at the time of conducting the experiments due to psychophysical experiment design considerations that require an equal incremental and decremental comparisons spread (maximum of 4 on each side). Selecting lower standard haptic stimuli bases would have made the comparisons spread go beyond the device's simulation capacity. Consequently, this research adopted factorial separation, which was calculated based on the high-end stimuli to ensure that they were just noticeable, while the low-end separation is double the intensity. Although low intensities were not used in this study, providing a factor-based list of absolute haptic weight and frictional texture stimuli will hopefully motivate further research in this direction.

One final issue is related to the choice of products and the product attributes that are evaluated in the shopping environments. Due to experimental design considerations (discussed in section 5.4.1.2), the shopping environments in this research only sell one type of products, i.e. massagers. While weight and massaging-surface experience are believed to be among the most important attributes of this type of products (McDonagh et al. 2005), other product attributes, such as brand and colour may be equally as important to the choices consumers make when shopping online (Lee and Lee 2009). For instance, consumers, who are loyal to a brand name, are more likely to pick the brand that they are loyal to than an unknown one. Hence, this research has excluded the use of brand names and colours. However, it may be necessary to replicate the study to observe the role of haptic product evaluation on the choices consumers make when other influential information, such as brand name, is present in order to examine the impact of haptic product evaluation on the consumer shopping experience. Replicating the study using different product types and subjects may also be important if we wish to determine the extent to which the observed findings can be generalised across different product and consumer types.

Chapter 7: Conclusion and Future Work

7.1 Introduction

This chapter briefly reviews the research presented in this thesis and summarises its achievements. It also discusses its general research contribution to the field of haptic perception as well as the use of haptic modality to enhance e-commerce information content. The chapter concludes with the limitations of the research and gives suggestions for the direction of future work.

7.2 Thesis Summary

Technology supporting the Internet has advanced rapidly, making it possible to shop at the comfort of the consumer’s home with less time and effort. Online shopping offers the advantage of easy access to a wide range of products that can be purchased locally and globally with competitive prices. The increased demand for online shopping has encouraged many businesses to expand beyond the physical storefront to the virtual space. For such an expansion, offering interactive and high-quality content to attain a competitive advantage has become fundamental to business success.

However, the availability of such technologies does not inevitably ensure that they positively influence business performance. There are many challenges that act as constraints and factors in implementing successful e-commerce businesses; these were addressed in section 2.4.4. Among these challenges is the inability to physically assess the quality of online products through touch and feel prior to ordering them. Such an important element in evaluating many products (Spence and Gallace 2011) cannot be delivered through the current traditional and long-established mouse-based GUI interaction. Consequently, in order to cater to this requirement, a different GUI interaction should be established.

In recent years, the haptic field has seen a continuously growing interest in science and engineering research (Saddik et al. 2011b). Through haptics interfaces, users can obtain information about virtual object properties, such as their weight, smoothness, and warmth. Nevertheless, the technology is faced with many challenges, which could slow the spread of the use of haptic interaction into wider areas of human needs, as discussed in section 2.2.3. While challenges do exist, providing a sufficient haptic impression of the products represents a desirable enhancement to online shopping. Similarly, the sort of visual impressions available in existing online retailers, despite obvious differences in the quality and availability of product images across online shopping websites, plays an important role in capturing users' attention (Lee and Benbasat 2003) and generating positive attitudes amongst users (Hong et al. 2004).

With the dearth of literature in the area of haptic online shopping, this thesis focused on using haptic feedback technology to enhance the online shopping experience in terms of providing shoppers with the ability to physically examine online products before the purchase is made. The primary aim of this thesis was to empirically investigate the use of haptic product information as an enhancement to textual product information to enhance online shopping experience (Chapter 5). In order to fulfil this aim, it was initially necessary to establish baseline information about human perception of simulated haptic weight (Chapter 3) and texture (Chapter 4) feedback information for an online shopping context through psychophysical evaluations. These aimed to investigate the smallest haptic stimuli difference (i.e., JND) needed to effectively discern between two close haptic stimuli levels for an online shopping context using psychophysical methods of measurement. This was important because current literature does not provide a decisive answer as to the JND required, since it depends on the experimental setup and the technology in use. Also, the investigation offered insight into the design space required for simulated haptic feedback to enable the modelling of various haptic elements of product information, which could eventually be evaluated by consumers who are shopping online.

7.3 Summary of Findings

The research first aimed to investigate the smallest haptic stimuli difference threshold (JND) needed to effectively discern between two close haptic stimuli levels for an online shopping context using psychophysical methods of measurement. Using the Phantom Omni device, the investigation demonstrated that:

- Although free haptic exploration was exercised on both experiments in order to more closely resemble traditional shopping, results were relatively consistent with previous work on haptic discrimination.
- The Weber Fraction JND for weight force discrimination, represented as downward forces along the *y*-axis, was 10.01 percent.

- The Weber Fraction JND for texture force discrimination, represented as friction forces, was 14.1 percent when using DynamicCF at any level of StaticCF.
- In light of the psychophysical experiments, haptic weights and textures stimuli values were produced to represent various products using the Weber Fraction JND percentage identified.

The results from the first aim of this research led to the conclusion that, despite the limitations in terms of its ability to simulate wide haptic properties, the device in use (i.e., Phantom Omni) is able to provide a reasonable number of absolute haptic stimuli, using factorial separation to allow for paired comparisons, as demonstrated in section 5.4.2. However, further psychophysical studies may be necessary to evaluate other standard haptic stimuli bases, especially lighter stimulus intensity, in order to provide a complete a list of absolute haptic weight and frictional texture stimuli.

The second aim of this research was to evaluate the use of haptic product information as an alternative to textual product information to enhance the electronic shopping experience. The results of this evaluation study show that:

- Even with a brief training session, subjects are able to interact with the Non-HPI and HPI environments using the haptic feedback device with 100 percent completion success rate.
- The availability of haptic product information does not necessarily impose different product choices, but it complements other information, such as price and appearance.

- Providing haptic product information does not lead to significant decrease or increase in time spent compared textual product information. However, there is a tendency to increase the time spent.
- Providing haptic product information does not lead to a significant decrease or increase in effort (i.e., number of actions) when compared to textual product information. However, there is a tendency to decrease the effort required to complete the tasks.
- In general, subjects' ratings suggested that both the Non-HPI and HPI environments shopping experiences were satisfactory in terms of overall satisfaction, product information usefulness, system ease of use, and confidence in the shopping decision. However, a significant increase in confidence was apparent for the HPI environment, depending on the task.

In reflecting on this comparative evaluation of haptic shopping between the Non-HPI to the HPI environments, several observations can be reported. The evaluation has shown that:

- Observation and subjects' comments (see section 5.8.3) suggest the overall haptic shopping experience was favourable. When comparing the Non-HPI to the HPI environments the, they expressed interest in the HPI environment.
- Although a non-familiar device was used throughout the experiments, which required moving along the *xyz*-axes, as well as rotating on each axis, subjects were able to adapt to the shopping environments quickly and with minimal training.
- For some of the subjects, 2.5D buttons prompted navigational difficulty, especially when there are many on-screen buttons.

- Subjects tended to compare each haptic property separately, rather experiencing the haptic properties of one product and comparing them to another product.
- Subjects exposed a desire for more engagement through 3D images of products with integrated haptic properties.
- While providing helpful assessment to the human hand, haptic information that is accessible to other parts of the human body may provide more relevant assessment.

The research presented in this study is the very first steps towards the development of advanced haptic-based environments in e-commerce and other associated professions. It offers a framework for evaluation of haptic properties for online shopping that can aid in determining the simulation capacity limit of other haptic devices. Furthermore, the research does not only lay the foundation for designing online haptic shopping, but also provides empirical support to research in this direction. However, investigations are needed to further confirm these findings, which will be discussed later in this chapter.

7.4 Significance of the Research

The findings of this research are significant to three key groups: researchers, designers of online shopping, and users of online shopping. These groups will be discussed in the next subsections.

7.4.1 Researchers

This research reports an investigation on haptic feedback and its role in enhancing electronic shopping. In particular, the reported findings give attention to the use of haptic feedback information to augment the traditional textual approach of presenting product information.

The initial set of experiments undertaken though this research involved a psychophysical evaluation of haptic weight and friction forces. The results of the evaluation identify a Weber Fraction JND percentage threshold using free haptic exploration to resemble traditional shopping activity. However, the results can be generalised to other applications, where comparisons of haptic stimuli are favourable, such as comparing products in online virtual environments (e.g., Secondlife.com), re-education of sensation in the hand after nerve injury and repair, or for providing navigational cues for blind people using the Web (Eid et al. 2007).

The final experiment in this research involved a comparative study on the user experience of haptic product information. This was conducted with the aim of developing a better understanding of the potential benefits of enhancing online shopping with haptic feedback interaction. It is meant to improve the usability of online shopping, where physical evaluation of products is difficult. This study was one of very few to consider haptic feedback in an electronic shopping context by comparing textual and haptic product information. Researchers can adopt both the psychophysical evaluation of haptic weight and friction forces, as well as the comparative study of haptic product information user experiences, to evaluate other haptic technologies (i.e., Novint Falcon) or environments (e.g., Secondlife.com)

7.4.2 Designers of Online Shopping

Although the online presence of businesses is a cost-effective way to reach out to a large number of global consumers, the lack of physical contact with products to gain tangible product information is likely to deter many from engaging in an online purchase (Childers et al. 2001). Below is a list of points that are of significance to the designers of online shopping.

1. The psychophysical evaluation of haptic weight and friction forces results can support designers of haptic shopping applications that need weight and frictional texture force discriminations to select appropriate absolute stimuli for the reliable perception of stimuli differences.

2. Should the Phantom Omni device be used, the results can also be used to identify upper-level constraints on the number of objects that can be simultaneously compared.

3. The results of the user experience evaluation of the haptic product information will enable designers to have a greater understanding of how haptic feedback is used to enhance the shopping experience.

4. The results of the user experience evaluation show that providing haptic product information did not affect the effectiveness and efficiency of the interaction when compared to the textual approach of conveying product information.

5. Haptic product information was shown to increase confidence in the shopping decision which could promote higher business profits through future revisits (Srinivasan et al. 2002; Lee and Kozar 2011).

Until the technology is widely available, the current results demonstrate a promising potential that constitutes a first step towards haptic feedback to enhance the shopping experience.

7.4.3 Users of Online Shopping

The results of this research are of significance interest to online shoppers. They show that, although the technology was new, the subjects of this research study found that interacting with the haptic environments was satisfactory in terms of overall satisfaction, product information usefulness, and system ease of use. The results also show increased confidence in the chosen products. Several issues and improvements were documented while observing the subjects' interactions (see section 5.8.3). By addressing these issues and improvements, the environments will be more likely to lead to a haptic shopping environment that meets the needs of the users.

Incorporating haptic interaction into online shopping could insure easy accessibility to people with special needs. Blind and visually impaired shoppers may see big benefits of haptic shopping as it could provide them with possibilities to experience product information that would be impossible otherwise.

7.5 Limitations

Generalisation beyond the present study is limited by (1) the sample population, (2) the capabilities of the haptic device use, (3) the weight and texture force simulation, (4) the haptic technology itself, (5) the shopping environment, and (6) the experimental setup.

1. Subjects of all experiments were students and staff from Durham University aged 18-39. If haptic online shopping is to be commonplace in the future, it would be helpful to consider a wider population range of subjects, including children teenagers, older adults and those with motor impairments. This would enable either general guidelines to be built or dynamic JND threshold calibration based on the current user to be supported.

2. The device used in this study, a Phantom Omni, is limited in terms of the forces it can simulate. Depending on the context of use, examination of the different thresholds at greater friction forces may be necessary. This will be important when comparing a number of objects. For instance, if three different frictional surfaces are to be compared at one time, would one high friction surface influence the perception of two lighter friction surfaces?

3. Weight forces were simulated as plain downwards-pushing forces on subjects' dominant hand. An examination of haptic gravity effects may be necessary to observe their influence on the perception of weights during active exploration. Similarly, surface damping and stiffness were held at constant values of 0 and 0.5, respectively, throughout the frictional texture

experiment. Experimenting with different damping and stiffness values may be necessary to observe their influence on the perception of DynamicCF during active exploration, and also to extend the number of friction stimuli.

4. The use of new haptic interaction technology (novelty) may have had an effect on the results obtained. Given that subjects had a limited time to interact with the environments during the course of the research, a longitudinal study may be more informative in this regard, especially when measuring haptic shopping user experience.

5. The haptic shopping environments offered only six products, and all of these were the same kind of product (i.e. massagers). Moreover, the environments' tasks were only carried out up to the point at which the product is added to the basket. The environments did not contain ordering or payment facilities to support the online shopping process. A wider selection of products and a fully functional ordering system would enable wider task scenarios with different difficulty levels to be tested and also provide a more representative online shopping environment.

6. All experiments were conducted in a lab setting so that subjects could be observed through systems logs and video recording. Such a setting is very artificial and does not represent a natural interaction that typically takes place in the home environment, especially in the case of the haptic shopping evaluation study.

7.6 Future Work

Based on the work presented in this thesis, there is evidence of several potential extensions to the current work that can be explored. These extensions are detailed below.

Since light haptic properties intensities require higher JNDs in order to be sensed by human subjects as suggested by Engens (1971, as cited in Gescheider 1997), further work is needed to evaluate other standard haptic feedback stimuli bases, especially lighter-intensity stimulus bases, in order be able to build a reliable list of absolute haptic weight and frictional texture stimuli. Such a list could help researchers conduct research more critically and efficiently, and could also help designers build more usable and more reliable haptic shopping content.

Another possible future research topic would the use of different haptic devices or properties. Replicating the current research with other cost-effective devices (such as the Novint Falcon haptic device or the Senseg tactile touch-screen) or other haptic properties (such as heavier weights, deformation, and roughness) may offer further support regarding the use of haptic feedback in online shopping. Besides providing empirical evidence, research in this direction will complement the current research efforts by providing a reliable list of absolute haptic stimuli. This could help designers convey haptic stimuli that are device-specific.

One more area of future research topic would the use of different UI controls. Examining different UI controls for haptic information (i.e. to convey product weights and product surface textures). Also, examining different button lay out, size, and shapes. Unlike web interface, UI controls in 2.5D interfaces are object that can obstruct the user while browsing which could impose usage and navigational difficulty especially when there are many on screen UI control objects. This can help build a more usable haptic application for e-commerce.

Ultimately, it is likely that future work on the above referred points while paying attention to the limitations of this research will make this study much more complete. It is hoped that the above points will help to shape the future directions of researchers interested in facilitating haptic feedback in online shopping.

Appendix A – Weight Discrimination Responses

	0.24	0.48	0.72	0.96	1.20	1.44	1.68	1.92	2.16		Transitions
P1	0	0	0	0	1	1	1	1	1		1.08
P2	0	0	0	0	0	0	1	1	1		1.56
P3	0	0	0	0	1	1	1	1	1		1.08
P4	0	0	0	0	1	1	1	1	1		1.08
P5	0	0	0	0	0	1	1	1	1		1.32
P6	0	0	0	0	0	1	1	1	1		1.32
P7	0	0	0	0	0	1	1	1	1		1.32
P8	0	0	0	0	1	1	1	1	1		1.08
P9	0	0	0	0	0	1	1	1	1		1.32
P10	0	0	0	0	1	1	1	1	1		1.08
P11	0	0	0	0	0	1	1	1	1		1.32
P12	0	0	0	0	0	0	1	1	1		1.56
P13	0	0	0	0	1	1	1	1	1		1.08
P14	0	0	0	0	1	1	1	1	1		1.08
P15	0	0	0	0	0	1	1	1	1		1.32
P16	0	0	0	0	1	1	1	1	1		1.08
P17	0	0	0	1	1	1	1	1	1		0.84
P18	0	0	0	0	1	1	1	1	1		1.08
P19	0	0	0	0	1	1	1	1	1		1.08
P20	0	0	0	0	1	1	1	1	1		1.08
P21	0	0	0	0	0	1	1	1	1		1.32
P22	0	0	0	0	0	1	1	1	1		1.32
P23	0	0	0	0	1	1	1	1	1		1.08
P24	0	0	0	0	0	1	1	1	1		1.32
Probability	0	0	0	0.042	0.54	0.92	1	1	1	**Mean of Transitions (MT)**	1.200
										SEM	0.035

Table A.1: Subjects' responses for haptic weight discrimination based on the 1.2 Newton force standard stimulus.

	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	2.70		Transitions
P1	0	0	0	0	1	1	1	1	1		1.35
P2	0	0	0	0	0	1	1	1	1		1.65
P3	0	0	0	0	0	0	1	1	1		1.95
P4	0	0	0	0	0	1	1	1	1		1.65
P5	0	0	0	0	1	1	1	1	1		1.35
P6	0	0	0	0	0	1	1	1	1		1.65
P7	0	0	0	0	0	1	1	1	1		1.65
P8	0	0	0	0	1	1	1	1	1		1.35
P9	0	0	0	0	0	1	1	1	1		1.65
P10	0	0	0	0	1	1	1	1	1		1.35
P11	0	0	0	0	1	1	1	1	1		1.35
P12	0	0	0	0	0	1	1	1	1		1.65
P13	0	0	0	0	0	1	1	1	1		1.65
P14	0	0	0	0	1	1	1	1	1		1.35
P15	0	0	0	0	1	1	1	1	1		1.35
P16	0	0	0	0	1	1	1	1	1		1.35
P17	0	0	0	0	1	1	1	1	1		1.35
P18	0	0	0	0	1	1	1	1	1		1.35
P19	0	0	0	0	0	1	1	1	1		1.65
P20	0	0	0	0	1	1	1	1	1		1.35
P21	0	0	0	0	1	1	1	1	1		1.35
P22	0	0	0	0	1	1	1	1	1		1.35
P23	0	0	0	0	0	1	1	1	1		1.65
P24	0	0	0	1	1	1	1	1	1		1.05
Probability	**0**	**0**	**0**	**0.042**	**0.58**	**0.96**	**1**	**1**	**1**	**Mean of Transitions (MT)**	1.475
										SEM	0.040

Table A.2: Subjects' responses for haptic weight discrimination based on the 1.5 Newton force standard stimulus.

	0.36	0.72	1.08	1.44	1.80	2.16	2.52	2.88	3.24		Transitions
P1	0	0	0	0	1	1	1	1	1		1.62
P2	0	0	0	0	1	1	1	1	1		1.62
P3	0	0	0	0	0	1	1	1	1		1.98
P4	0	0	0	0	1	1	1	1	1		1.62
P5	0	0	0	0	1	1	1	1	1		1.62
P6	0	0	0	0	1	1	1	1	1		1.62
P7	0	0	0	0	0	1	1	1	1		1.98
P8	0	0	0	0	1	1	1	1	1		1.62
P9	0	0	0	0	0	0	1	1	1		2.34
P10	0	0	0	0	0	1	1	1	1		1.98
P11	0	0	0	0	0	1	1	1	1		1.98
P12	0	0	0	0	0	1	1	1	1		1.98
P13	0	0	0	0	0	1	1	1	1		1.98
P14	0	0	0	0	0	1	1	1	1		1.98
P15	0	0	0	0	0	1	1	1	1		1.98
P16	0	0	0	0	0	1	1	1	1		1.98
P17	0	0	0	0	0	1	1	1	1		1.98
P18	0	0	0	0	1	1	1	1	1		1.62
P19	0	0	0	0	0	1	1	1	1		1.98
P20	0	0	0	1	1	1	1	1	1		1.26
P21	0	0	0	0	1	1	1	1	1		1.62
P22	0	0	0	0	0	1	1	1	1		1.98
P23	0	0	0	0	0	0	1	1	1		2.34
P24	0	0	0	0	1	1	1	1	1		1.62
Probability	**0**	**0**	**0**	**0.042**	**0.42**	**0.92**	**1**	**1**	**1**	**Mean of Transitions (MT)**	1.845
										SEM	0.052

Table A.3: Subjects' responses for haptic weight discrimination based on the 1.8 Newton force standard stimulus.

Appendix B – Friction Discrimination Responses

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9		Transitions
P1	1	1	1	1	1	1	0	0	0		0.65
P2	1	1	1	1	0	0	0	0	0		0.45
P3	1	1	1	1	0	0	0	0	0		0.45
P4	1	1	1	1	1	0	0	0	0		0.55
P5	1	1	1	1	1	1	0	0	0		0.65
P6	1	1	1	1	0	0	0	0	0		0.45
P7	1	1	1	1	1	0	0	0	0		0.55
P8	1	1	1	1	1	0	0	0	0		0.55
P9	1	1	1	1	1	0	0	0	0		0.55
P10	1	1	1	1	0	0	0	0	0		0.45
P11	1	1	1	1	1	0	0	0	0		0.55
P12	1	1	1	1	0	0	0	0	0		0.45
P13	1	1	1	1	1	1	0	0	0		0.65
P14	1	1	1	1	1	1	0	0	0		0.65
P15	1	1	1	1	1	0	0	0	0		0.55
P16	1	1	1	1	1	1	0	0	0		0.65
P17	1	1	1	1	0	0	0	0	0		0.45
P18	1	1	1	1	1	0	0	0	0		0.55
P19	1	1	1	1	1	0	0	0	0		0.55
P20	1	1	1	0	0	0	0	0	0		0.35
Probability	1	1	1	0.95	0.65	0.25	0	0	0	**Mean of Transitions (MT)**	0.535
										SEM	0.020

Table B.1: Subjects' responses for haptic friction discrimination based on the 0.5 standard DynamicCF at level 0.1 of StaticCF.

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9		Transitions
P1	1	1	1	1	1	0	0	0	0		0.55
P2	1	1	1	1	0	0	0	0	0		0.45
P3	1	1	1	1	1	0	0	0	0		0.45
P4	1	1	1	1	1	1	0	0	0		0.65
P5	1	1	1	1	0	0	0	0	0		0.45
P6	1	1	1	0	0	0	0	0	0		0.35
P7	1	1	1	1	0	0	0	0	0		0.45
P8	1	1	1	0	0	0	0	0	0		0.35
P9	1	1	1	1	1	0	0	0	0		0.55
P10	1	1	1	1	1	0	0	0	0		0.55
P11	1	1	1	1	0	0	0	0	0		0.45
P12	1	1	1	0	0	0	0	0	0		0.35
P13	1	1	1	1	0	0	0	0	0		0.45
P14	1	1	1	1	1	0	0	0	0		0.55
P15	1	1	1	0	0	0	0	0	0		0.35
P16	1	1	1	1	0	0	0	0	0		0.45
P17	1	1	1	1	0	0	0	0	0		0.45
P18	1	1	1	1	1	1	0	0	0		0.65
P19	1	1	1	0	0	0	0	0	0		0.35
P20	1	1	1	1	0	0	0	0	0		0.45
Probability	**1**	**1**	**1**	**0.75**	**0.35**	**0.1**	**0**	**0**	**0**	**Mean of Transitions (MT)**	0.465
										SEM	0.020

Table B.2: Subjects’ responses for haptic friction discrimination based on the 0.5 standard DynamicCF at level 0.3 of StaticCF.

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9		Transitions
P1	1	1	1	1	0	0	0	0	0		0.45
P2	1	1	1	1	0	0	0	0	0		0.45
P3	1	1	1	1	1	0	0	0	0		0.55
P4	1	1	1	1	1	0	0	0	0		0.55
P5	1	1	1	1	1	0	0	0	0		0.55
P6	1	1	1	0	0	0	0	0	0		0.35
P7	1	1	1	0	0	0	0	0	0		0.35
P8	1	1	1	0	0	0	0	0	0		0.35
P9	1	1	1	1	0	0	0	0	0		0.45
P10	1	1	1	1	0	0	0	0	0		0.45
P11	1	1	1	1	1	0	0	0	0		0.55
P12	1	1	1	0	0	0	0	0	0		0.35
P13	1	1	1	1	0	0	0	0	0		0.45
P14	1	1	1	1	1	1	1	0	0		0.75
P15	1	1	0	0	0	0	0	0	0		0.25
P16	1	1	1	1	0	0	0	0	0		0.45
P17	1	1	1	0	0	0	0	0	0		0.35
P18	1	1	1	1	1	0	0	0	0		0.55
P19	1	1	1	1	1	1	1	0	0		0.75
P20	1	1	1	1	1	0	0	0	0		0.55
Probability	**1**	**1**	**0.95**	**0.7**	**0.4**	**0.1**	**0.1**	**0**	**0**	**Mean of Transitions (MT)**	0.475
										SEM	0.029

Table B.3: Subjects' responses for haptic friction discrimination based on the 0.5 standard DynamicCF at level 0.5 of StaticCF.

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9		Transitions
P1	1	1	1	1	0	0	0	0	0		0.45
P2	1	1	1	1	0	0	0	0	0		0.45
P3	1	1	1	1	0	0	0	0	0		0.45
P4	1	1	1	1	0	0	0	0	0		0.45
P5	1	1	1	1	1	0	0	0	0		0.55
P6	1	1	1	0	0	0	0	0	0		0.35
P7	1	1	0	0	0	0	0	0	0		0.25
P8	1	1	1	1	1	1	1	0	0		0.75
P9	1	1	1	1	0	0	0	0	0		0.45
P10	1	1	1	1	1	0	0	0	0		0.55
P11	1	1	1	1	0	0	0	0	0		0.45
P12	1	1	1	0	0	0	0	0	0		0.35
P13	1	1	1	1	1	0	0	0	0		0.55
P14	1	1	1	0	0	0	0	0	0		0.35
P15	1	1	1	1	0	0	0	0	0		0.45
P16	1	1	1	1	1	0	0	0	0		0.55
P17	1	1	1	1	1	1	0	0	0		0.65
P18	1	1	1	0	0	0	0	0	0		0.35
P19	1	1	1	0	0	0	0	0	0		0.35
P20	1	1	1	1	1	0	0	0	0		0.55
Probability	**1**	**1**	**0.95**	**0.7**	**0.35**	**0.1**	**0.05**	**0**	**0**	**Mean of Transitions (MT)**	0.465
										SEM	0.026

Table B.4: Subjects' responses for haptic friction discrimination based on the 0.5 standard DynamicCF at level 0.7 of StaticCF.

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9		Transitions
P1	1	1	1	1	0	0	0	0	0		0.45
P2	1	1	1	1	0	0	0	0	0		0.35
P3	1	1	1	0	0	0	0	0	0		0.45
P4	1	1	1	1	1	0	0	0	0		0.55
P5	1	1	1	1	1	0	0	0	0		0.55
P6	1	1	1	1	0	0	0	0	0		0.45
P7	1	1	1	1	0	0	0	0	0		0.35
P8	1	1	1	0	0	0	0	0	0		0.35
P9	1	1	1	1	0	0	0	0	0		0.5
P10	1	1	1	1	0	0	0	0	0		0.4
P11	1	1	1	1	1	1	0	0	0		0.65
P12	1	1	1	1	1	1	0	0	0		0.65
P13	1	1	1	1	0	0	0	0	0		0.45
P14	1	1	1	1	1	0	0	0	0		0.55
P15	1	1	1	1	0	0	0	0	0		0.45
P16	1	1	1	1	0	0	0	0	0		0.45
P17	1	1	0	0	0	0	0	0	0		0.25
P18	1	1	1	0	0	0	0	0	0		0.4
P19	1	1	1	1	1	0	0	0	0		0.5
P20	1	1	1	0	0	0	0	0	0		0.4
Probability	**1**	**1**	**0.95**	**0.75**	**0.3**	**0.1**	**0**	**0**	**0**	**Mean of Transitions (MT)**	0.458
										SEM	0.022

Table B.5: Subjects' responses for haptic friction discrimination based on the 0.5 standard DynamicCF at level 0.9 of StaticCF.

Appendix C – Nielson’s Heuristics Evaluation

No.	Usability Heuristics	Application
1	Simple and natural dialogue	Related products information is displayed close together and was also given a distinctive background colour. The use of colours was minimal and only when needed to categorise, differentiate and highlight (see section 5.4). Uppercase text was avoided.
2	Speaks the user’s language	System-oriented terms avoided. Words, phrases and concepts familiar to the user were used instead, e.g. “Compare”, “Add to Compare” and “” Add to Basket”.
3	Minimise user memory load	Subjects have the choice to compare product information individually as well as in pairs so that they do not have to remember information from one part of the dialogue to another.
4	Consistency	All information was presented in the same location and was formatted in the same way so that subjects do not have to wonder whether different words, situations, or actions mean the same thing.
5	Feedback	The environment keep subjects informed about what is going on, through appropriate feedback messages when needed.
6	Clearly marked exits	N/A
7	Shortcuts	N/A
8	Good error message	Clear language was used avoiding system-oriented terms. Error messages explain what subjects should do using polite language.
9	Prevent errors	N/A
10	Help and documentation	N/A

Table C.1: Nielson’s heuristics used to evaluate the haptic shopping environments (Nielsen 1993, pp. 115 - 155).

Appendix D – Shopping Environments Screenshots

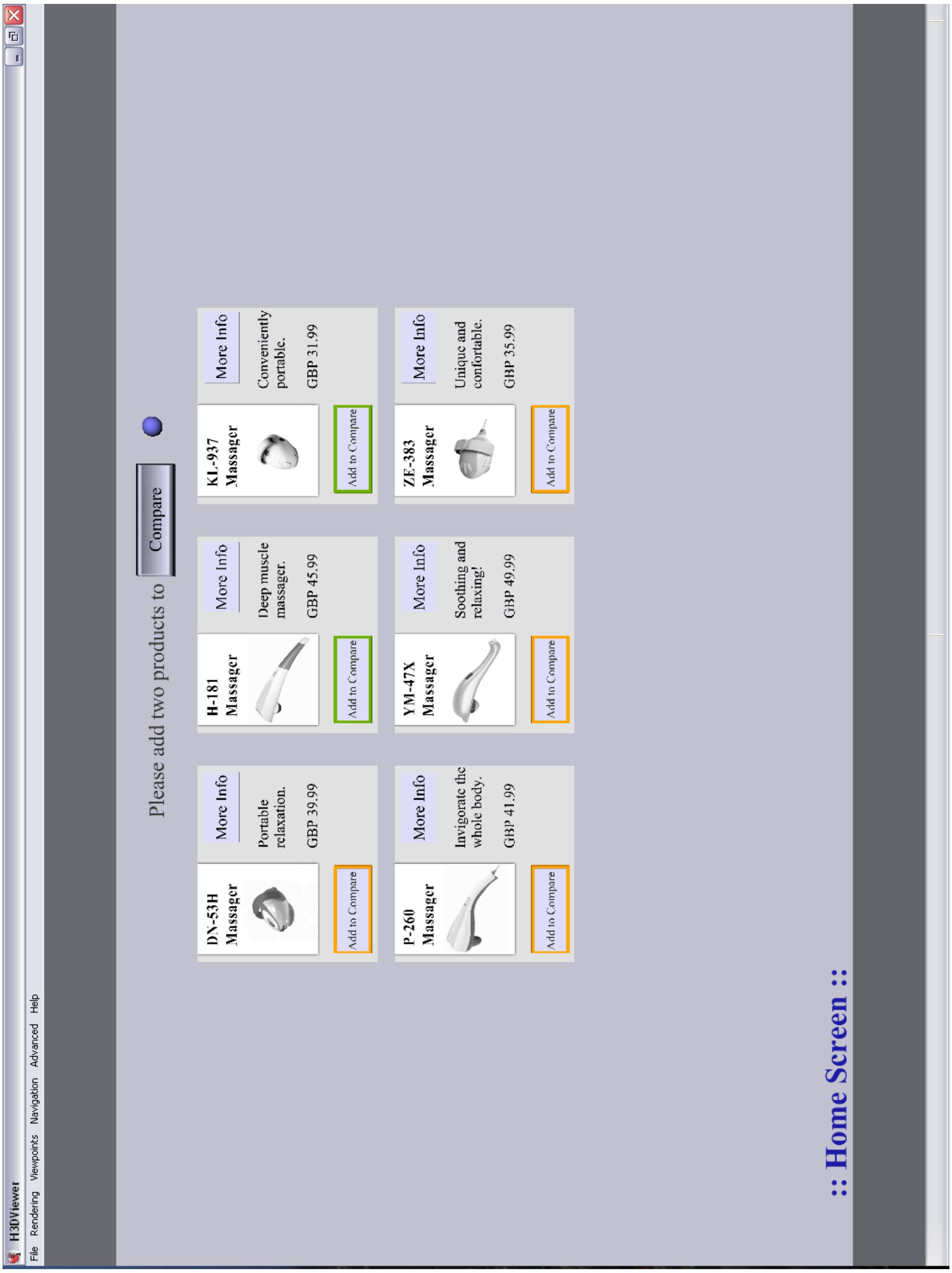


Figure D.1: HPI and Non-HPI systems had the same Home Screen.

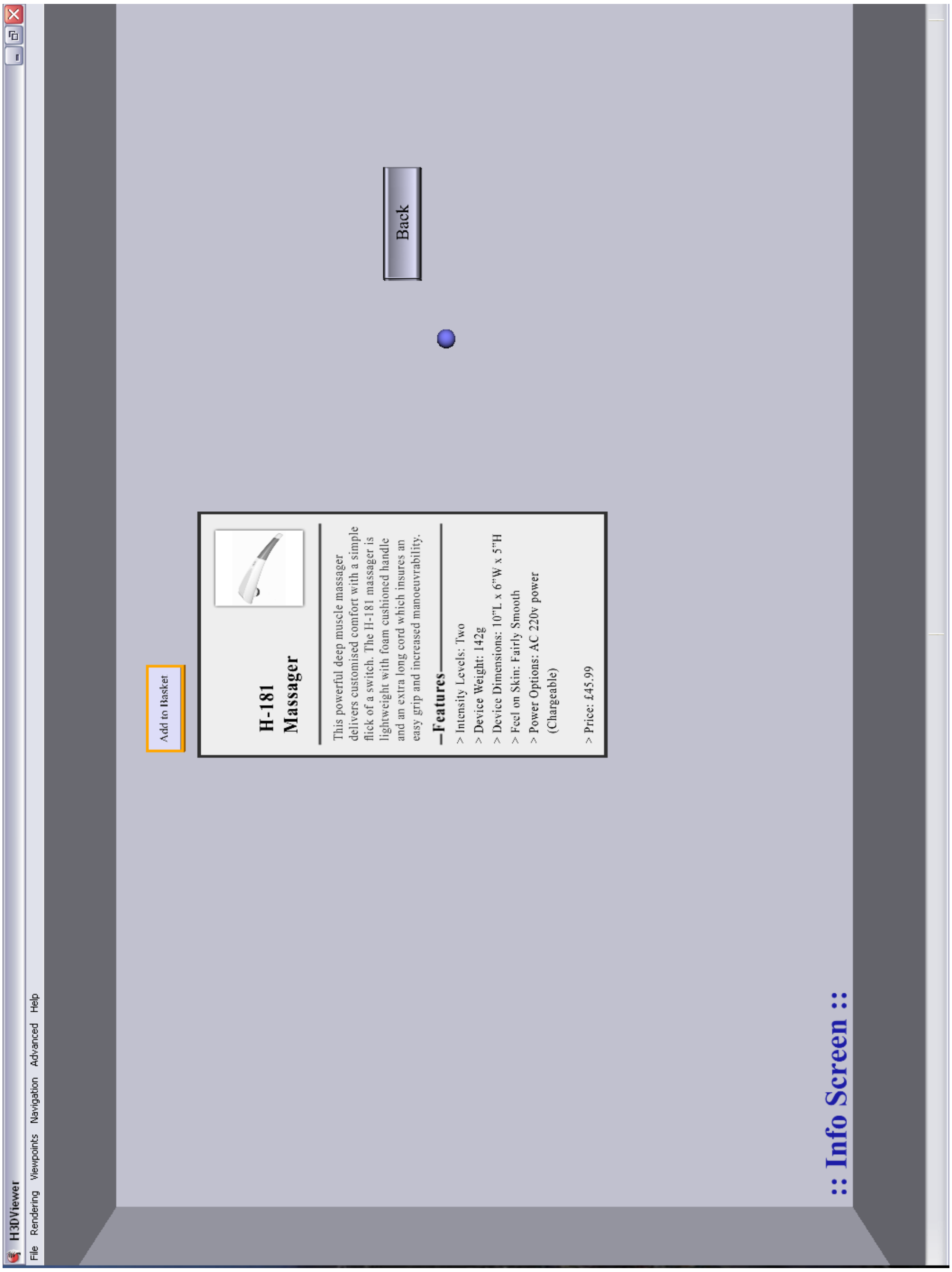


Figure D.2: Example of Info Screen for Non-HPI system

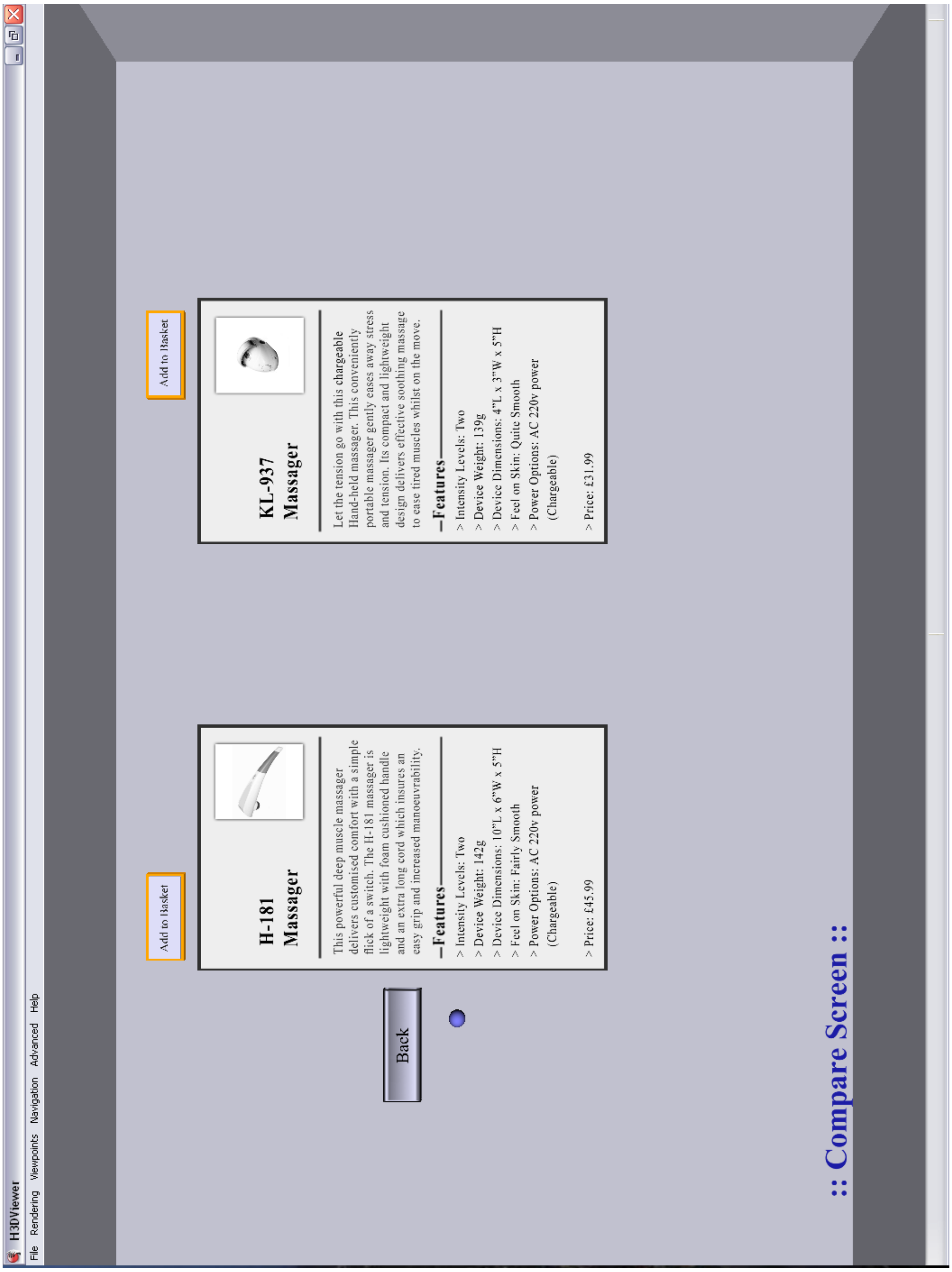


Figure D.3: Example of Compare Screen for Non-HPI system

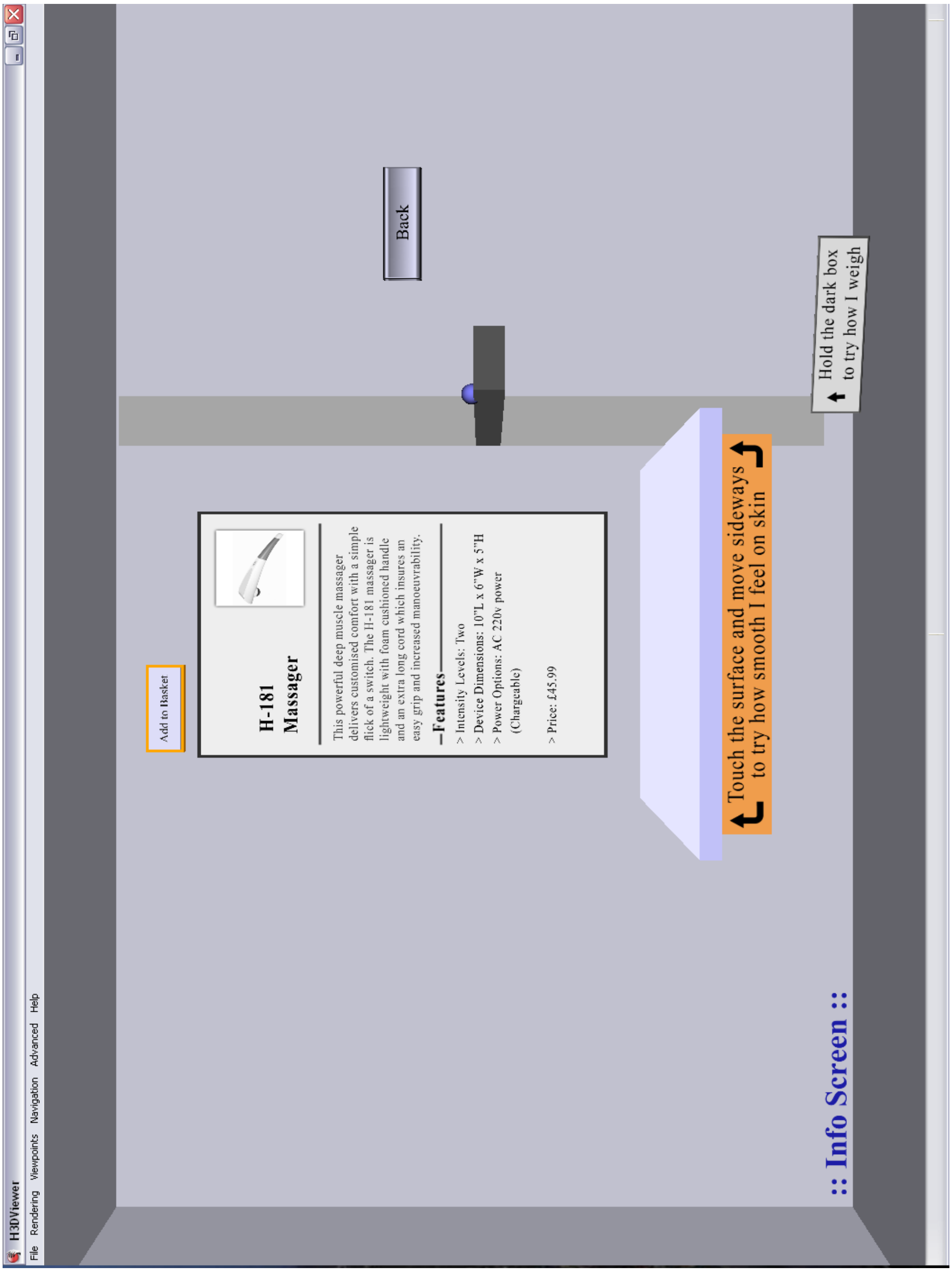


Figure D.4: Example of Info Screen for HPI system

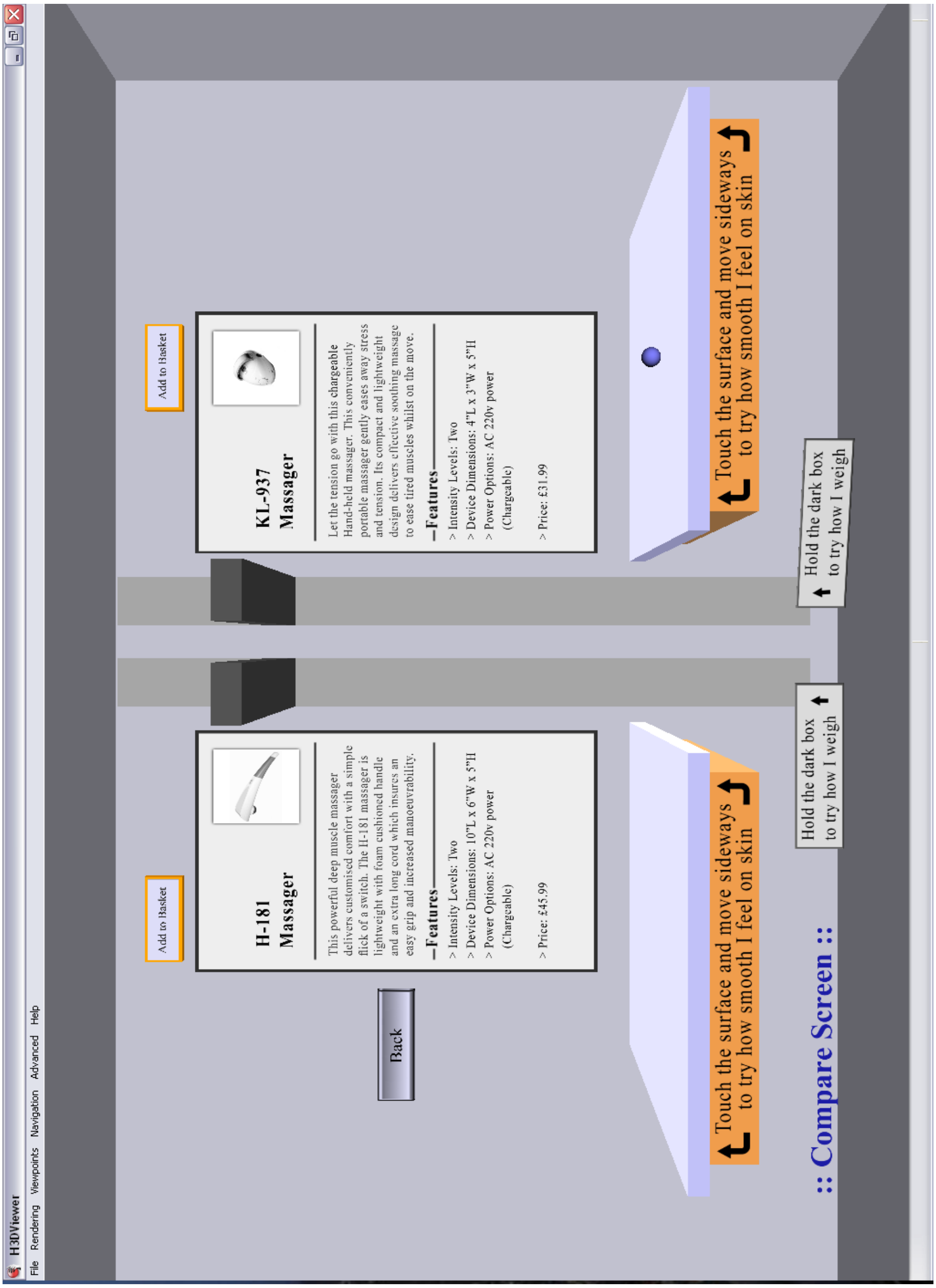


Figure D.5: Example of Compare Screen for HPI system

Appendix E – Self-Reporting Questionnaires

PRE-SESSION QUESTIONNAIRE

Candidate ID: ....
Date: ....

1 What is your gender?

☐ Male ☐ Female

2 In what age group are you?

☐ 18-25 ☐ 26-32 ☐ 33-39
☐ 40-46 ☐ 47-51 ☐ 52+

3 How often do you shop online?

☐ Never ☐ Occasionally ☐ Often

4 How often do you play 3D games (e.g. Doom, Quake, etc.)?

☐ Never ☐ Occasionally ☐ Often

5 Have you ever used virtual reality devices to interact with virtual objects?

☐ Yes. *Please specify:* ....
☐ No.

(i) If yes, how would you rate your level of expertise with the devices?

☐ Novice
☐ Experienced
☐ Expert

POST-SESSION QUESTIONNAIRE

#	**Please answer the following question.**
1	Which product information helped you the most in your selection? (Please tick all that apply.)

- ☐ The product image
- ☐ The product description
- ☐ Intensity levels
- ☐ Device weight
- ☐ Device dimension
- ☐ Feel on skin
- ☐ Power options
- ☐ Price

- ☐ Other *Please specify:* ....

2	Why do you think the product information selected above were helpful?

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POST-SESSION QUESTIONNAIRE

#	Below is a list of statements. We would like you to rate each one by circling one of the numbers.				
1	Please rate your overall satisfaction of the system.	Not Satisfied			Very Satisfied
		1	2	3	4
2	Please rate the usefulness of the product information provided.	Not Useful			Very Useful
		1	2	3	4
3	Please rate the system ease of use.	Difficult to Use			Easy to Use
		1	2	3	4
4	Please rate your confidence level for your shopping decision based on the product information given by the system.	Not Confident			Very Confident
		1	2	3	4

 # Please feel free to make any comments about the system, positive or negative, that you would like to add below.

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= = Thank you for your participation = =

Appendix F – Consent Forms

VIRTUAL SHOPPING EVALUATION

Date: ________________________
Candidate ID: _________________

Consent Form

Thank you for volunteering to participate in this evaluation of virtual shopping. You will participate in a short interaction with a virtual store and will complete two shopping tasks. You will then be asked to fill out a questionnaire about your experience. The interaction will take approximately 15-20 minutes and we will be videotaping the session for review. Your total time involved will be no more than 25 minutes. The researchers appreciate your candid and direct feedback. All information you give us will be kept confidential. Your identity will remain confidential to the extent provided by the law. There are no direct risks to you by participating in this study. The recording of the session will be only reviewed and kept by the researchers. You may withdraw your participation at any time. Thank you.

The subject should complete the whole of this sheet himself/herself

Have you had an opportunity to ask questions and to discuss the study?

[ ] YES [ ] NO

Have you received satisfactory answers to all of your questions?

[ ] YES [ ] NO

Have you received enough information about the study?

[ ] YES [ ] NO

Who have you spoken to? ______________________________________

Do you understand that you are free to withdraw from the study at any time and without having to give a reason for withdrawing?

[ ] YES [ ] NO

I have read the procedure described above and I voluntarily agree to participate in this study and have received a copy of this description

Signed ....………................
Date ....…...

(NAME IN BLOCK LETTERS) ....………..............………........

Voluntary Release of Video

I grant the researchers (Durham University) permission to use the video of my participation in the Virtual Shopping Evaluation. The videos are to be used in scholarly publications. I understand that I am not obligated to complete this part of the consent form and it will in no way impact my participation in the study. I understand that my name and personal information will be kept with strict confidentiality.

Signed ....………..................

Date ....…...

(NAME IN BLOCK LETTERS) ....………..............……........

Appendix G – Haptic Shopping Introductory Script

Virtual Shopping Evaluation

This activity is intended to evaluate new shopping environments. We have solicited your help because we need an independent view of how well the systems operate. Your role is to perform tasks (that will be described to you shortly) and fill-out questionnaires relating to the system in use.

Since the system is new to you, you can take as much time as you wish (within reason) to complete the task. During the session, I will be a silent observer. I will not talk to you or ask any questions while you are interacting with the system. However, you are free to ask questions or bring up concerns at any time.

This session will be videotaped. My job is to observe the steps you take in performing your assessment and record your interactions or any other event that cannot have been captured by the video-recorder.

Evaluation Steps for system 1 & 2:

1) Read system 1 task-scenario.
2) Use the system to find suitable product for the task.
3) Add the product of your choice to basket.
4) Fill-out the post-session questionnaire.

5) Read system 2 task-scenario and repeat steps 2-4.

Appendix H – Haptic Shopping Data and Statistical Tests

1. Time Spent Data

Users	System	Task	Time (Sec.)		System	Task	Time (Sec.)
P1	HPI	Hiking (T1)	134		Non-HPI	Fitness (T2)	125
P3	HPI	Hiking (T1)	136		Non-HPI	Fitness (T2)	94
P4	HPI	Hiking (T1)	414		Non-HPI	Fitness (T2)	234
P7	HPI	Hiking (T1)	151		Non-HPI	Fitness (T2)	97
P11	HPI	Hiking (T1)	233		Non-HPI	Fitness (T2)	282
P14	HPI	Hiking (T1)	124		Non-HPI	Fitness (T2)	110
P16	HPI	Hiking (T1)	305		Non-HPI	Fitness (T2)	184
P17	HPI	Hiking (T1)	126		Non-HPI	Fitness (T2)	99
P18	HPI	Hiking (T1)	248		Non-HPI	Fitness (T2)	160
P19	HPI	Hiking (T1)	65		Non-HPI	Fitness (T2)	97
P20	HPI	Hiking (T1)	306		Non-HPI	Fitness (T2)	143
P22	HPI	Hiking (T1)	367		Non-HPI	Fitness (T2)	264
		Mean	**217.42**			**Mean**	**157.42**
		SEM	**22.70**			**SEM**	**13.99**
P2	Non-HPI	Hiking (T1)	217		HPI	Fitness (T2)	227
P5	Non-HPI	Hiking (T1)	95		HPI	Fitness (T2)	196
P6	Non-HPI	Hiking (T1)	294		HPI	Fitness (T2)	292
P8	Non-HPI	Hiking (T1)	113		HPI	Fitness (T2)	276
P9	Non-HPI	Hiking (T1)	129		HPI	Fitness (T2)	177
P10	Non-HPI	Hiking (T1)	146		HPI	Fitness (T2)	115
P12	Non-HPI	Hiking (T1)	79		HPI	Fitness (T2)	163
P13	Non-HPI	Hiking (T1)	108		HPI	Fitness (T2)	250
P15	Non-HPI	Hiking (T1)	163		HPI	Fitness (T2)	215
P21	Non-HPI	Hiking (T1)	170		HPI	Fitness (T2)	256
P23	Non-HPI	Hiking (T1)	163		HPI	Fitness (T2)	243
P24	Non-HPI	Hiking (T1)	106		HPI	Fitness (T2)	186
		Mean	**148.58**			**Mean**	**216.33**
		SEM	**12.24**			**SEM**	**10.45**

1.1. Tests of Normality

Shapiro-Wilk test for Task2 using the NonHPI environment indicates a deviation from normality ($p < .05$).

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	System	Statistic	df	Sig.	Statistic	df	Sig.
Task1	NonHPI	.194	12	.200	.886	12	.105
	HPI	.225	12	.095	.922	12	.301
Task2	NonHPI	.182	12	.200*	.847	12	.034
	HPI	.115	12	.200*	.978	12	.975

2. Button Clicks Data

Users	System	Task	Clicks		System	Task	Clicks
P1	HPI	Hiking (T1)	1		Non-HPI	Fitness (T2)	3
P3	HPI	Hiking (T1)	1		Non-HPI	Fitness (T2)	1
P4	HPI	Hiking (T1)	5		Non-HPI	Fitness (T2)	5
P7	HPI	Hiking (T1)	1		Non-HPI	Fitness (T2)	1
P11	HPI	Hiking (T1)	6		Non-HPI	Fitness (T2)	8
P14	HPI	Hiking (T1)	4		Non-HPI	Fitness (T2)	3
P16	HPI	Hiking (T1)	6		Non-HPI	Fitness (T2)	7
P17	HPI	Hiking (T1)	2		Non-HPI	Fitness (T2)	4
P18	HPI	Hiking (T1)	9		Non-HPI	Fitness (T2)	7
P19	HPI	Hiking (T1)	2		Non-HPI	Fitness (T2)	4
P20	HPI	Hiking (T1)	6		Non-HPI	Fitness (T2)	8
P22	HPI	Hiking (T1)	3		Non-HPI	Fitness (T2)	5
		Mean	**3.83**			**Mean**	**4.67**
		SEM	**0.53**			**SEM**	**0.50**
P2	Non-HPI	Hiking (T1)	8		HPI	Fitness (T2)	6
P5	Non-HPI	Hiking (T1)	4		HPI	Fitness (T2)	5
P6	Non-HPI	Hiking (T1)	5		HPI	Fitness (T2)	3
P8	Non-HPI	Hiking (T1)	4		HPI	Fitness (T2)	2
P9	Non-HPI	Hiking (T1)	4		HPI	Fitness (T2)	1
P10	Non-HPI	Hiking (T1)	1		HPI	Fitness (T2)	1
P12	Non-HPI	Hiking (T1)	5		HPI	Fitness (T2)	2
P13	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	5
P15	Non-HPI	Hiking (T1)	4		HPI	Fitness (T2)	1
P21	Non-HPI	Hiking (T1)	5		HPI	Fitness (T2)	6
P23	Non-HPI	Hiking (T1)	8		HPI	Fitness (T2)	8
P24	Non-HPI	Hiking (T1)	5		HPI	Fitness (T2)	8
		Mean	**4.67**			**Mean**	**4.00**
		SEM	**0.39**			**SEM**	**0.54**

2.1. Tests of Normality

Kolmogorov-Smirnov test for Task1 using the NonHPI environment indicates a deviation from normality ($p < .05$).

	System	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Task1	NonHPI	.265	12	.020	.889	12	.113
	HPI	.177	12	.200[*]	.903	12	.176
Task2	NonHPI	.162	12	.200[*]	.926	12	.338
	HPI	.190	12	.200[*]	.885	12	.100

3. Product Selections

Users	System	Task	Selected Massager Code		System	Task	Selected Massager Code
P1	HPI	Hiking (T1)	3		Non-HPI	Fitness (T2)	4
P3	HPI	Hiking (T1)	3		Non-HPI	Fitness (T2)	5
P4	HPI	Hiking (T1)	3		Non-HPI	Fitness (T2)	3
P7	HPI	Hiking (T1)	2		Non-HPI	Fitness (T2)	1
P11	HPI	Hiking (T1)	4		Non-HPI	Fitness (T2)	3
P14	HPI	Hiking (T1)	3		Non-HPI	Fitness (T2)	4
P16	HPI	Hiking (T1)	5		Non-HPI	Fitness (T2)	5
P17	HPI	Hiking (T1)	3		Non-HPI	Fitness (T2)	2
P18	HPI	Hiking (T1)	3		Non-HPI	Fitness (T2)	4
P19	HPI	Hiking (T1)	3		Non-HPI	Fitness (T2)	5
P20	HPI	Hiking (T1)	2		Non-HPI	Fitness (T2)	4
P22	HPI	Hiking (T1)	3		Non-HPI	Fitness (T2)	2
P2	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	4
P5	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	2
P6	Non-HPI	Hiking (T1)	5		HPI	Fitness (T2)	5
P8	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	4
P9	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	5
P10	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	4
P12	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	5
P13	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	4
P15	Non-HPI	Hiking (T1)	4		HPI	Fitness (T2)	5
P21	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	3
P23	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	3
P24	Non-HPI	Hiking (T1)	3		HPI	Fitness (T2)	2

4. Which product information helped you the most in your selection?

	Task1 (Hiking)		Task 2 (Fitness Centre)	
Features	**Non-HPI**	**HPI**	**Non-HPI**	**HPI**
Image	41.67%	66.67%	50.00%	50.00%
Intensity	16.67%	8.33%	16.67%	25.00%
Weight	83.33%	83.33%	33.33% *	91.67% *
Dimension	25.00%	33.33%	8.33%	8.33%
Feel	25.00%	16.67%	8.33% *	66.67% *
Power	41.67%	50.00%	33.33% *	0.00% *
Price	66.67%	41.67%	66.67%	66.67%

*($p < 0.05$, McNemar test)

5. Subjects' Satisfaction

	Task 1 (Hiking)							
	Satisfaction		**Usefulness**		**Ease of Use**		**Confidence**	
	Non-HPI	HPI	Non-HPI	HPI	Non-HPI	HPI	Non-HPI	HPI
	2	4	2	4	3	3	2	4
	2	3	2	3	2	3	3	2
	2	4	3	3	3	3	3	3
	2	3	4	4	3	4	3	4
	3	2	3	3	3	2	3	3
	4	3	4	4	4	3	4	4
	3	3	4	4	3	4	3	3
	3	3	3	4	3	4	2	4
	4	2	4	4	3	2	4	2
	3	4	2	4	2	4	2	3
	4	3	4	3	4	2	4	3
	1	3	4	3	2	3	3	3
Mean	**2.750**	**3.083**	**3.250**	**3.583**	**2.917**	**3.083**	**3.000**	**3.167**
SE	**0.197**	**0.136**	**0.177**	**0.105**	**0.136**	**0.162**	**0.151**	**0.147**

	Task 2 (Fitness Centre)							
	Satisfaction		**Usefulness**		**Ease of Use**		**Confidence ***	
	Non-HPI	HPI	Non-HPI	HPI	Non-HPI	HPI	Non-HPI	HPI
	4	3	4	3	3	2	4	2
	2	3	3	2	4	3	2	3
	3	4	3	2	4	4	3	4
	3	2	3	4	4	3	3	4
	2	3	3	3	2	2	3	3
	3	3	4	3	3	3	4	4
	2	4	3	4	4	3	3	4
	3	4	4	4	4	4	2	4
	4	4	3	4	4	4	3	4
	4	4	4	2	4	3	3	4
	2	4	2	3	2	3	2	4
	3	2	3	4	3	3	3	3
Mean	**2.917**	**3.333**	**3.250**	**3.167**	**3.417**	**3.083**	**2.917**	**3.583**
SE	**0.162**	**0.159**	**0.127**	**0.170**	**0.162**	**0.136**	**0.136**	**0.136**

*($p < .5$, Sign test)

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